Water Quality Special Study Report

U.S. Army Corps of Engineers
Omaha District

Water Quality Conditions Monitored at the Corps' Garrison Project in North Dakota during the 3-Year Period 2003 through 2005

Aerial Photo of Garrison Dam and Lake Sakakawea

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(Report Number: CENWO-ED-HA/WQSS/Garrison/2006)

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps) Garrison Project consists of Garrison Dam and the reservoir impounded behind it – Lake Sakakawea. Garrison Dam is located on the Missouri River in central North Dakota about 75 miles northwest of Bismarck, North Dakota. The lake and dam are authorized for the uses of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Recreation at Lake Sakakawea is of great economic importance to the State of North Dakota, especially with respect to the lake's fishery. Lake Sakakawea currently maintains a "two-story" fishery that is comprised of warmwater, coolwater, and coldwater species. The ability of the lake to maintain a "two-story" fishery is due to the lake's thermal stratification in the summer into a colder bottom region and warmer surface region.

Water quality monitoring was conducted at the Garrison Project by the Omaha District over the 3-year period 2003 to 2005. The water quality monitoring conducted included: 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) continuous monitoring (i.e., hourly) of water quality conditions in the powerhouse of water discharged through Garrison Dam; 3) intensive water quality surveys in 2003, 2004, and 2005; and 4) a special water quality study in 2005. The results of this monitoring were used to assess the existing water quality conditions of Lake Sakakawea.

Overall, the existing water quality conditions monitored in Lake Sakakawea were good; however, a concern exists regarding the maintenance of coldwater habitat in the lake under the low pool levels associated with the ongoing drought conditions. Water quality conditions in Lake Sakakawea vary significantly along the length of the lake, and strong thermal stratification occurs in the deeper area of the lake during the summer. Water quality monitoring indicates that the lacustrine zone of Lake Sakakawea is mesotrophic, while the riverine and transition zone of the lake are eutrophic to moderately eutrophic. The phytoplankton community of Lake Sakakawea was dominated by diatoms, with only minor "blooms" of cyanobacteria.

With the exception of late summer, the water discharged through Garrison Dam exhibited very good water quality. During September of 2003 and 2004, monitoring indicated that North Dakota's water quality standards criterion for dissolved oxygen of at least 5 mg/l was not met in the water discharged through Garrison Dam during minimum flow releases. This situation did not occur in 2005.

As drought conditions persisted in early 2005, water levels in Lake Sakakawea had fallen to a record low pool elevation of 1805.8 feet-msl on May 12, 2005. At that time it was felt that, unless emergency water quality management measures were implemented in 2005 to preserve the coldwater habitat in Lake Sakakawea, the recreational sport fishery would likely be adversely impacted. The reduction of coldwater habitat is exacerbated by the releases from the Garrison Dam intake structure. Because the invert elevation of the intake portals to the Garrison Dam power tunnels (i.e., penstocks) is 2 feet above the lake bottom, water drawn through the penstocks comes largely from the lower depths of Lake Sakakawea. Thus, during the summer thermal stratification period, water is largely drawn from the coldwater habitat volume of Lake Sakakawea. Three short-term water quality management measures were identified for implementation in an effort to preserve the coldwater habitat in Lake Sakakawea. These measures, which were implemented at the Garrison Dam, included: 1) modification of the dam's intake trash racks, 2) utilization of head gates to restrict the opening to the dam's power tunnels, and 3) modification of the daily flow cycle and minimum flow releases from the dam. The three implemented water quality management measures were targeted at drawing water into the dam from higher elevations within Lake Sakakawea.

No change in water quality conditions measured in Lake Sakakawea was discernable due to the implementation of the short-term water quality management measures. However, based on water quality monitoring of the water discharged through Garrison Dam, it appears that up to 379,390 acre-feet of water meeting optimal coldwater habitat criteria were prevented from being discharged through Garrison Dam and retained in Lake Sakakawea due to the implementation of the short-term water quality management measures. Implementation of the short-term water quality management measures warmed the water that was discharged through Garrison Dam in the late summer by 2 to 4°C. How far downstream the Missouri River this warming was detectable and any possible consequences have not been determined at this time. The implemented water quality management measures also had the effect of raising dissolved oxygen concentrations in the water discharged through Garrison Dam in late summer under minimum flow releases. Although the short-term water quality management measures were implemented to preserve coldwater habitat in Lake Sakakawea, they also had the probable benefit of allowing the State of North Dakota’s water quality standards criterion for dissolved oxygen to be met in the Missouri River immediately below Garrison Dam during late summer minimum flow releases.

The Omaha District is currently pursuing the application of the Corps’ CE-QUAL-W2 (Version 3.2) hydrodynamic and water quality model to Lake Sakakawea. CE-QUAL-W2 is an extremely powerful tool to aid in addressing reservoir water quality management issues. Application of the CE-QUAL-W2 model will allow the Corps to better understand how the operation of the Garrison Project affects the water quality of Lake Sakakawea and the Missouri River below Garrison Dam. It is almost a certainty that water quality issues at the Garrison Project will remain important in the future.

1 INTRODUCTION

1.1 RECENT WATER QUALITY MONITORING AT THE CORPS' GARRISON PROJECT

Water quality monitoring conducted by the Omaha District at the Garrison Project over the past 3 years included 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) continuous monitoring (i.e., hourly) of water quality conditions in the powerhouse of water discharged through Garrison Dam; 3) intensive water quality surveys in 2003, 2004, and 2005; and 4) a special water quality study in 2005. The continuing long-term, fixed-station monitoring consisted of monthly (i.e., May through September) field measurements and sample collection. The monitoring in the Garrison powerhouse was on water drawn from the penstocks prior to passing through the dam's turbines. The intensive surveys included monitoring at seven additional in-lake sites approximately equally spaced from near the Four Bear Bridge at New Town, North Dakota to Garrison Dam, and monitoring the Missouri and Little Missouri River inflows to the lake. The special study monitoring conducted in 2005 involved measuring water quality conditions along the submerged intake channel in Lake Sakakawea near Garrison Dam. This report presents the findings of the water quality monitoring conducted by the Omaha District at the Garrison Project during the period 2003 though 2005.

1.2 DESCRIPTION OF THE GARRISON PROJECT

Garrison Dam is located in central North Dakota on the Missouri River at River Mile (RM) 1390, about 75 miles northwest of Bismarck, North Dakota and 11 miles south of the town of Garrison, North Dakota. Construction of the project was initiated in 1946, and dam closure in 1953 resulted in the formation of Lake Sakakawea. Garrison Dam is currently the fifth largest earthen dam in the world. The Garrison Project is one of six projects located on the mainstem of the Missouri River. The project is part of a hydraulically and electrically integrated system that is regulated to obtain the optimum fulfillment of the multipurpose benefits for which the mainstem reservoirs were authorized and constructed. The Missouri River Mainstem System is operated under the guidelines described in the reservoir regulation manual "Master Manual" (USACE-RCC, 2004a). The "Master Manual" details operation for the flood control, multipurpose, and emergency regulation procedures in accordance with the authorized purposes. The lake and dam are authorized for the uses of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. The lake is used as a water supply by some individual cabins and by the cities of Four Bears, Mandaree, Park City, Parshall, Riverdale, Trenton, Twin Buttes, and Williston, North Dakota. Lake Sakakawea is an important recreational resource and a major visitor destination in North Dakota.

Lake Sakakawea is the largest Corps reservoir. When full, Lake Sakakawea is 178 miles long and up to 6 miles wide. The lake contains almost a third of the total storage capacity of the Missouri River Mainstem System, nearly 24 million acre-feet (MAF). Table 1.1 summarizes how the surface area, volume, mean depth, and retention time of Lake Sakakawea vary with pool elevations. Lake Sakakawea first reached its minimum operating level in late 1955. Due to drought conditions it was not until 10 years later, in 1965, that the Carryover Multiple Use Zone was first filled. Generally, it remained filled from that time through 2002, except for the two drought periods to date (1988 through 1993 and 2000 through present). Exclusive flood control storage space was used in 1969, 1975, 1995, and 1997. During 1975, all flood control space was filled and the maximum reservoir level was 0.8 foot above the top of the Exclusive Flood Control Zone, elevation 1854.8 feet-msl. Due to ongoing drought conditions, the lake is

Table 1.1. Surface area, volume, mean depth, and retention time of Lake Sakakawea at different lake pool elevations.

Elevation (Feet-msl)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1855	384,480	24,203,180	63.0	1.52
1850	364,265	22,331,620	61.3	1.40
1845	344,460	20,558,360	59.7	1.29
1840	320,600	18,893,560	58.9	1.18
1835	296,210	17,355,220	58.6	1.09
1830	280,520	15,916,490	56.7	1.00
1825	263,525	14,556,980	55.2	0.91
1820	249,665	13,275,410	53.2	0.83
1815	235,600	12,061,430	51.2	0.76
1810	219,955	10,921,980	49.7	0.68
1805	204,453	9,861,138	48.2	0.62
1800	188,998	8,877,219	47.0	0.56
1795	173,070	7,973,682	46.1	0.50
1790	161,295	7,139,184	44.3	0.45
1785	148,759	6,364,791	42.8	0.40
1780	138,809	5,646,736	40.7	0.35
1775	128,261	4,979,890	38.8	0.31

Average Annual Inflow (1967 through 2005) = 16.69 Million Acre-Feet
Average Annual Outflow: (1967 through 2005) = 15.95 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.

currently (i.e., December 2005) more than 25 feet below the top of the Carryover Multiple Use Zone, but 6 feet above the record low set in May 2005. Major inflows to Lake Sakakawea are the Missouri River, Yellowstone River, and Little Missouri River. Water discharged through Garrison Dam for power production is withdrawn from Lake Sakakawea at elevation 1672 – approximately 2 feet above the lake bottom.

1.3 WATER QUALITY MANAGEMENT CONCERNS AT THE GARRISON PROJECT

1.3.1 APPLICABLE WATER QUALITY STANDARDS

1.3.1.1 Lake Sakakawea

Pursuant to the Federal Clean Water Act (CWA), the State of North Dakota has designated Lake Sakakawea as a Class 1 lake in the State's water quality standards. As such, the lake is to be suitable for the propagation and/or protection of a coldwater fishery (i.e., salmonid fishes and associated aquatic biota); swimming, boating, and other water recreation; irrigation; stock watering; wildlife; and for municipal or domestic use after appropriate treatment.

1.3.1.2 Missouri River below Garrison Dam

The Missouri River below Garrison Dam has been designated as a Class 1 stream by the State of North Dakota. As such, the river is to be suitable for the propagation and/or protection of resident fish species and other aquatic biota and for swimming, boating, and other water recreation. The quality of the waters shall be for irrigation, stock watering, and wildlife without injurious effects. After treatment, consisting of coagulation, settling, filtration, and chlorination, or equivalent treatment processes, the water quality shall meet the bacteriological, physical, and chemical requirements of the State for municipal or domestic use. The tailwaters area of the Missouri River below Garrison Dam is not classified separately from the rest of the river; however, the tailwaters area does support a coldwater fishery.

1.3.2 FEDERAL CLEAN WATER ACT SECTION 303(D) IMPAIRED WATER BODY LISTINGS

Pursuant to the Federal CWA, the State of North Dakota has placed Lake Sakakawea on the State's Section 303(d) list of impaired waters. The cited reason for this listing is impairment to the uses of fish and other aquatic biota and fish consumption due to the pollutants/stressors of low dissolved oxygen, water temperature, and methyl-mercury. The State of North Dakota has issued a fish consumption advisory for Lake Sakakawea due to mercury concerns.

1.3.3 MAINTENANCE OF A "TWO-STORY" RECREATIONAL FISHERY IN LAKE SAKAKAWEA

Recreation at Lake Sakakawea is of great economic importance to the State of North Dakota, especially with respect to the lake's fishery. Lake Sakakawea currently maintains a "two-story" fishery in that the lake fishery is comprised of warmwater, coolwater, and coldwater species. The ability of the lake to maintain a "two-story" fishery is due to the lake's thermal stratification in the summer into a colder bottom region and warmer surface region. Coolwater and warmwater species present in the lake that are recreationally important include walleye (*Sander vitreus*), sauger (*Sander canadensis*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), catfish (*Ictalurus spp.*), and yellow perch (*Perca flavescens*). The Chinook salmon (*Oncorhynchus tshawytscha*) is a coldwater species of recreational importance that is maintained in the lake through regular stocking. The primary forage fish utilized by all sport fishes in the lake is the rainbow smelt (*Osmerus mordax*) – a coldwater species. Since it is the primary forage fish in Lake Sakakawea, fluctuations in the smelt population have a ripple effect throughout the lake's entire recreational sport fishery. The recent pool level drawdowns of Lake Sakakawea, due to the ongoing drought conditions in the interior western United States, have reduced the amount of coldwater habitat available in Lake Sakakawea. If the current recreational sport fishery of Lake Sakakawea is to be supported, adequate coldwater habitat to meet the needs of Chinook salmon and rainbow smelt needs to be maintained.

Two water quality parameters, temperature and dissolved oxygen, are of prime importance regarding the maintenance of coldwater fishery habitat in Lake Sakakawea. As the pool level of Lake Sakakawea falls, the amount of coldwater habitat available at lower lake depths during summer thermal stratification is reduced. During summer thermal stratification, the lake is also experiencing degradation of dissolved oxygen at lower lake depths as accumulated organic matter is decomposed. The situation is most critical later in the summer when the reduced volume of colder water combined with the degradation of dissolved oxygen in the deeper water of the lake act together to limit the coldwater habitat volume.

1.3.4 MANAGEMENT OF WATER QUALITY FOR OTHER USERS

Two water users draw water directly from the penstocks at Garrison Dam. These users are the Corps' Garrison Powerplant which draws water for turbine cooling, and the U.S. Fish and Wildlife Service (USFWS) which draws water to support fish culturing and rearing at the Garrison federal fish hatchery located near Garrison Dam. Both of these users require colder water to meet their needs. Warmer water limits the Corps' ability to effectively cool the dam's turbines, and the USFWS's ability to culture and raise coldwater species – notably Chinook salmon.

1.4 IMPLEMENTATION OF SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

As drought conditions persisted in early 2005, water levels in Lake Sakakawea had fallen to a record low pool elevation of 1805.8 feet-msl on May 12, 2005. At that time it was felt that unless emergency water quality management measures were implemented in 2005 to preserve the coldwater habitat in Lake Sakakawea, the recreational sport fishery would likely be adversely impacted. The reduction of coldwater habitat is exacerbated by withdrawals from the Garrison Dam intake structure. Because the invert elevation of the intake portals to the Garrison Dam power tunnels (i.e., penstocks) is 2 feet above the lake bottom, water drawn through the penstocks comes largely from the lower depths of Lake Sakakawea. Thus, during the summer thermal-stratification period, water is largely drawn from the coldwater habitat volume of Lake Sakakawea. Three short-term water quality management measures were identified for implementation in an effort to preserve the coldwater habitat in Lake Sakakawea. These measures, which were implemented at Garrison Dam, included: 1) modification of the dam's intake trash racks, 2) utilization of head gates to restrict the opening to the dam's power tunnels, and 3) modification of the daily flow cycle and minimum flow releases from the dam. The three implemented water quality management measures were targeted at drawing water into the dam from higher elevations within Lake Sakakawea.

2 WATER QUALITY MONITORING CONSIDERATIONS

2.1 WATER QUALITY MONITORING OBJECTIVES

2.1.1 GENERAL MONITORING OBJECTIVES

The Omaha District has identified five goals and 16 monitoring objectives for surface water quality monitoring to facilitate implementation of the District's Water Quality Management Program (USACE, 2005a). The water quality monitoring conducted at the Garrison Project the past 3 years was implemented to address 7 of the 16 identified monitoring objectives. The 7 general water quality monitoring objectives that were addressed are:

- Characterize the spatial and temporal distribution of water quality conditions at Corps projects.
- Determine if water quality conditions attributed to the operation of Corps projects are improving, degrading, or staying the same over time.
- Determine if water quality conditions at Corps projects or attributable to the operation of Corps Projects (i.e., downstream conditions resulting from reservoir discharges) meet applicable Federal, State, and Local water quality standards.
- Assess water quality conditions at Corps projects in relation to potential sources, transport, fate, and effects of contaminants.
- Identify pollutants and their sources that are affecting water quality and the aquatic environment at Corps projects.
- Calibrate and validate water quality and watershed models used to access water quality concerns at Corps projects.
- Collect information needed to design, engineer, and implement measures or modifications at Corps projects to enhance surface water quality and the aquatic environment.

2.1.2 SPECIFIC MONITORING OBJECTIVES

In addition to the seven general water quality monitoring objectives, two specific monitoring objectives were identified for the intensive water quality surveys of Lake Sakakawea:

1) Collect empirical data that allows for the estimation of the spatial extent of coldwater fish habitat in Lake Sakakawea from June (thermocline establishment) through September (fall turnover).
2) Collect the information needed to allow application and "full calibration" of the Version 3.2 CE-QUAL-W2 hydrodynamic and water quality model to Lake Sakakawea.

2.2 LIMNOLOGICAL CONSIDERATIONS

2.2.1 VERTICAL AND LONGITUDINAL WATER QUALITY GRADIENTS

The annual temperature distribution represents one of the most important limnological processes occurring within a reservoir. Thermal variation in a reservoir results in temperature-induced density stratification, and an understanding of the thermal regime is essential to water quality assessment. Deep, temperate-zone lakes typically completely mix from the surface to the bottom twice a year (i.e., dimictic). Temperature-zone dimictic lakes exhibit thermally-induced density stratification in the summer and winter months that is separated by periods of "turnover" in the spring and fall (i.e., Lake Sakakawea). This stratification typically occurs through the interaction of wind and solar insolation at the lake surface and creates density gradients that can influence lake water quality. During the summer, solar insolation has its highest intensity and the reservoir becomes stratified into three zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion.

Epilimnion: The epilimnion is the upper zone that consists of the less dense, warmer water in the reservoir. It is fairly turbulent since its thickness is determined by the turbulent kinetic energy inputs (e.g., wind, convection, etc.), and a relatively uniform temperature distribution throughout this zone is maintained.

Metalimnion: The metalimnion is the middle zone that represents the transition from warm surface water to cooler bottom water. There is a distinct temperature gradient through the metalimnion. The metalimnion contains the thermocline that is the plane or surface of maximum temperature rate change.

Hypolimnion: The hypolimnion is the bottom zone of the more dense, colder water that is relatively quiescent. Bottom withdrawal or fluctuating water levels in reservoirs, however, may significantly increase hypolimnetic mixing.

Long, dendritic reservoirs, with tributary inflows located a considerable distance from the outflow and unidirectional flow from headwater to dam (i.e., Lake Sakakawea), develop gradients in space and time (USACE, 1987). Although these gradients are continuous from headwater to dam, three characteristic zones result: a riverine zone, a zone of transition, and a lacustrine zone (USACE, 1987).

Riverine Zone: The riverine zone is relatively narrow, well mixed, and although water current velocities are decreasing, advective forces are still sufficient to transport significant quantities of suspended particles, such as silts, clays, and organic particulate. Light penetration in this zone is minimal and may be the limiting factor that controls primary productivity in the water column. The decomposition of tributary organic loadings often creates a significant oxygen demand, but an aerobic environment is maintained because the riverine zone is generally shallow and well mixed. Longitudinal dispersion may be an important process in this zone.

Zone of Transition: Significant sedimentation occurs through the transition zone, with a subsequent increase in light penetration. Light penetration may increase gradually or abruptly, depending on the flow regime. At some point within the mixed layer of the zone of transition, a compensation point between the production and decomposition of organic matter should be reached. Beyond this point, production of organic matter within the reservoir mixed layer should begin to dominate.

Lacustrine Zone: The lacustrine zone is characteristic of a lake system. Sedimentation of inorganic particulate is low; light penetration is sufficient to promote primary production, with nutrient levels the limiting factor; and production of organic matter exceeds decomposition within the mixed layer. Entrainment of metalimnetic and hypolimnetic water, particulate, and nutrients may occur through internal waves or wind mixing during the passage of large weather fronts. Hypolimnetic mixing may be more extensive in reservoirs than "natural" lakes because of bottom withdrawal. In addition, an intake structure may simultaneously remove water from the hypolimnion and metalimnion.

When tributary inflow enters a reservoir, it displaces the reservoir water. If there is no density difference between the inflow and reservoir waters, the inflow moves as a density current in the form of overflows, interflows, or underflows. Internal mixing is the term used to describe mixing within a reservoir from such factors as wind, Langmuir circulation, convection, Kelvin-Helmholtz instabilities, and outflow (USACE, 1987).

2.2.2 CHEMICAL CHARACTERISTICS OF RESERVOIR PROCESSES

2.2.2.1 Constituents

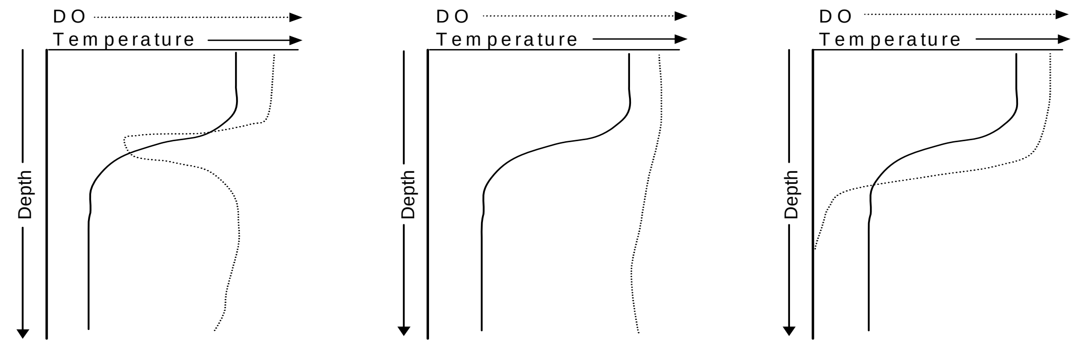
Some of the most important chemical constituents in reservoir waters that affect water quality are needed by aquatic organisms for survival. These include oxygen, carbon, nitrogen, and phosphorus. Other important constituents are silica, manganese, iron, and sulfur.

Dissolved oxygen: Oxygen is a fundamental chemical constituent of water bodies that is essential to the survival of aquatic organisms and is one of the most important indicators of reservoir water quality conditions. The distribution of dissolved oxygen (DO) in reservoirs is a result of dynamic transfer processes from the atmospheric and photosynthetic sources to consumptive uses by the aquatic biota. The resulting distribution of DO in the reservoir water strongly affects the solubility of many inorganic chemical constituents. Often, water quality control or management approaches are formulated to maintain an aerobic or oxic (i.e., oxygen-containing) environment. Oxygen is produced by aquatic plants (phytoplankton and macrophytes) and is consumed by aquatic plants, other biological organisms, and chemical oxidations. In reservoirs, the DO demand may be divided into two separate but highly interactive fractions: sediment oxygen demand (SOD) and water column oxygen demand.

Sediment oxygen demand: The SOD is typically highest in the upstream area of the reservoir just below the headwater. This is an area of transition from riverine to lake characteristics. It is relatively shallow but stratifies. The loading and sedimentation of organic matter is high in this transition area and, during stratification, the hypolimnetic DO to satisfy this demand can be depleted. If anoxic conditions develop, they generally do so in this area of the reservoir and progressively move toward the dam during the stratification period. The SOD is relatively independent of DO when DO concentrations in the water column are greater than 3 to 4 mg/l, but becomes limited by the rate of oxygen supply to the sediments.

Water column oxygen demand: A characteristic of many reservoirs is a metalimnetic minimum in DO concentrations or negative heterograde oxygen curve (Figure 2.1). Density interflows not only transport oxygen-demanding material into the metalimnion, but can also entrain reduced chemicals from the upstream anoxic area and create additional oxygen demand. Organic matter and organisms from the mixed layer settle at slower rates in the metalimnion because of increased viscosity due to lower temperatures. Since this labile organic matter remains in the metalimnion for a longer time period, decomposition occurs over a longer time, exerting a high oxygen demand. Metalimnetic oxygen depletion is an important process in deep reservoirs. A hypolimnetic oxygen demand generally starts at the sediment/water interface unless underflows contribute organic matter that exerts a significant oxygen demand. In addition to metalimnetic DO depletion, hypolimnetic DO depletion also is important in shallow, stratified reservoirs since there is a smaller hypolimnetic volume of oxygen to satisfy oxygen demands than in deep reservoirs.

Dissolved oxygen distribution: Two basic types of vertical DO distribution may occur in the water column: an orthograde and clinograde DO distribution (Figure 2.1). In the orthograde distribution, DO concentration is a function primarily of temperature, since DO consumption is limited. The clinograde DO profile is representative of more productive, nutrient-rich reservoirs where the hypolimnetic DO concentration progressively decreases during stratification and can occur during both summer and winter stratification periods.



Negative Heterograde Orthograde Clinograde

Figure 2.1. Vertical dissolved oxygen concentrations possible in thermally stratified lakes.

Inorganic carbon: Inorganic carbon represents the basic building block for the production of organic matter by plants. Inorganic carbon can also regulate the pH and buffering capacity or alkalinity of aquatic systems. Inorganic carbon exists in a dynamic equilibrium in three major forms: carbon dioxide (CO_2), bicarbonate ions (HCO_3), and carbonate ions (CO_3). Carbon dioxide is readily soluble in water and some CO_2 remains in a gaseous form, but the majority of the CO_2 forms carbonic acid that dissociates rapidly into HCO_3 and CO_3 ions. This dissociation results in a weakly alkaline system (i.e., pH $\approx$ 7.1 or 7.2). There is an inverse relationship between pH and CO_2. The pH increases when aquatic plants (phytoplankton or macrophytes) remove CO_2 from the water to form organic matter through photosynthesis during the day. During the night when aquatic plants respire and release CO_2, the pH decreases. The extent of this pH change provides an indication of the buffering capacity of the system. Weakly buffered systems with low alkalinities (i.e., <500 microequivalents per liter) experience larger shifts in pH than well-buffered systems (i.e., >1,000 microequivalents per liter).

Nitrogen: Nitrogen is important in the formulation of plant and animal protein. Nitrogen, similar to carbon, also has a gaseous form. Many species of cyanobacteria can use or fix elemental or gaseous N_2 as a nitrogen source. The most common forms of nitrogen in aquatic systems are ammonia (NH_3-N), nitrite (NO_2-N), and nitrate (NO_3-N). All three forms are transported in water in a dissolved phase. Ammonia results primarily from the decomposition of organic matter. Nitrite is primarily an intermediate compound in the oxidation or nitrification of ammonia to nitrate, while nitrate is the stable oxidation state of nitrogen and represents the other primary inorganic nitrogen form besides NH_3 used by aquatic plants.

Phosphorus: Phosphorus is used by both plants and animals to form enzymes and vitamins and to store energy in organic matter. Phosphorus has received considerable attention as the nutrient controlling algal production and densities and associated water quality problems. The reasons for this emphasis are: phosphorus tends to limit plant growth more than the other major nutrients; phosphorus does not have a gaseous phase and ultimately originates from the weathering of rocks; removal of phosphorus from point sources can reduce the growth of aquatic plants; and the technology for removing phosphorus is more advanced and less expensive than nitrogen removal. Phosphorus is generally expressed in terms of the chemical procedures used for measurement: total phosphorus, particulate phosphorus, dissolved or filterable phosphorus, and soluble reactive phosphorus. Phosphorus is a very reactive element; it reacts with many cations such as iron and calcium and is readily sorbed on particulate matter such as clays, carbonates, and inorganic colloids. Since phosphorus exists in a particulate phase, sedimentation represents a continuous loss from the water column to the sediment. Sediment phosphorus, then, may exhibit longitudinal gradients in reservoirs similar to sediment silt/clay gradients. Phosphorus contributions from sediment under anoxic conditions and macrophyte decomposition are considered internal phosphorus sources or loads, are in a chemical form available for plankton uptake and use, and can represent a major portion of the phosphorus budget.

Silica: Silica is an essential component of diatom algal frustules or cell walls. Silica uptake by diatoms can markedly reduce silica concentrations in the epilimnion and initiate a seasonal succession of diatom species. When silica concentrations decrease below 0.5 mg/l, diatoms generally are no longer competitive with other phytoplankton species.

Other nutrients: Iron, manganese, and sulfur concentrations generally are adequate to satisfy plant nutrient requirements. Oxidized iron (III) and manganese (IV) are quite insoluble in water and occur in low concentrations under aerobic conditions. Under aerobic conditions, sulfur usually is present as sulfate.

2.2.2.2 Anaerobic (Anoxic) Conditions

When dissolved oxygen concentrations in the hypolimnion are reduced to approximately 2 to 3 mg/l, the oxygen regime at the sediment/water interface is generally considered anoxic, and anaerobic processes begin to occur in the sediment interstitial water. Nitrate reduction to ammonium and/or N_2O or N_2 (denitrification) is considered to be the first phase of the anaerobic process and places the system in a slightly reduced electrochemical state. Ammonium-nitrogen begins to accumulate in the hypolimnetic water. The presence of nitrate prevents the production of additional reduced forms such as manganese (II), iron (II), or sulfide species. Denitrification probably serves as the main mechanism for removing nitrate from the hypolimnion. Following the reduction or denitrification of nitrate, manganese species are reduced from insoluble forms (i.e., Mn (IV)) to soluble manganous forms (i.e.,Mn (II)), which diffuse into the overlying water column. Nitrate reduction is an important step in anaerobic processes since the presence of nitrate in the water column will inhibit manganese reduction. As the electrochemical potential of the system becomes further reduced, iron is reduced from the insoluble ferric (III) form to the soluble ferrous (II) form, and begins to diffuse into the overlying water column. Phosphorus, in many instances, is also transported in a complexed form with insoluble ferric (III) species so the reduction and solubilization of iron also result in the release and solubilization of phosphorus into the water column. The sediments may serve as a major phosphorus source during anoxic periods and a phosphorus sink during aerobic periods. During this period of anaerobiosis, microorganisms also are decomposing organic matter into lower molecular weight acids and alcohols such as acetic, fulvic, humic, and citric acids and methanol. These compounds may also serve as trihalomethane precursors (low-molecular weight organic compounds in water; i.e., methane, formate acetate), which, when subject to chlorination during water treatment, form trihalomethanes, or THMs (carcinogens). As the system becomes further reduced, sulfate is reduced to sulfide, which begins to appear in the water column. Sulfide will readily combine with soluble reduced iron (II), however, to form insoluble ferrous sulfide, which precipitates out of solution. If the sulfate is reduced to sulfide and the electrochemical potential is strongly reducing, methane formation from the reduced organic acids and alcohols may occur. Consequently, water samples from anoxic depths will exhibit these chemical characteristics.

Anaerobic processes are generally initiated in the upstream portion of the hypolimnion where organic loading from the inflow is relatively high and the volume of the hypolimnion is minimal, so oxygen depletion occurs rapidly. Anaerobic conditions are generally initiated at the sediment/water interface and gradually diffuse into the overlying water column and downstream toward the dam. Anoxic conditions may also develop in a deep pocket near the dam due to decomposition of autochthonous organic matter settling to the bottom. This anoxic pocket, in addition to expanding vertically into the water column, may also move upstream and eventually meet the anoxic zone moving downstream.

Anoxic conditions are generally associated with the hypolimnion, but anoxic conditions may occur in the metalimnion. The metalimnion may become anoxic due to microbial respiration and decomposition of plankton settling into the metalimnion, microbial metabolism of organic matter entering as an interflow, or through entrainment of anoxic hypolimnetic water from the upper portion of the reservoir.

2.2.3 BIOLOGICAL CHARACTERISTICS AND PROCESSES

2.2.3.1 Microbiological

The microorganisms associated with reservoirs may be categorized as pathogenic or nonpathogenic. Pathogenic microorganisms are of a concern from a human health standpoint and may limit recreational and other uses of reservoirs. Nonpathogenic microorganisms are important in that they often serve as decomposers of organic matter and are a major source of carbon and energy for a reservoir. Microorganisms generally inhabit all zones of the reservoir as well as all layers. Seasonally high concentrations of bacteria will occur during the warmer months, but they can be diluted by high discharges. Anaerobic conditions enhance growth of certain bacteria while aeration facilitates the use of bacterial food sources. Microorganisms, bacteria in particular, are responsible for mobilization of contaminants from sediments.

2.2.3.2 Photosynthesis

Oxygen is a by-product of aquatic plant photosynthesis, which represents a major source of oxygen for reservoirs during the growing season. Oxygen solubility is less during the period of higher water temperatures, and diffusion may also be less if wind speeds are lower during the summer than the spring or fall. Biological activity and oxygen demand typically are high during thermal stratification, so photosynthesis may represent a major source of oxygen during this period. Oxygen supersaturation in the euphotic zone can occur during periods of high photosynthesis.

2.2.3.3 Plankton

Phytoplankton influence dissolved oxygen and suspended solids concentrations, transparency, taste and odor, aesthetics, and other factors that affect reservoir uses and water quality objectives. Phytoplankton are a primary source of organic matter production and form the base of the autochthonous food web in many reservoirs since fluctuating water levels may limit macrophyte and periphyton production. Phytoplankton can be generally grouped as diatoms, green algae, cyanobacteria, or cryptomonad algae. Chlorophyll *a* represents a common variable used to estimate phytoplankton biomass.

Seasonal succession of phytoplankton species is a natural occurrence in lakes and reservoirs. The spring assemblage is usually dominated by diatoms and cryptomonads. Silica depletion in the photic zone and increased settling as viscosity decreases because of increased temperatures usually result in green algae succeeding the diatoms. Decreases in nitrogen or a decreased competitive advantage for carbon at higher pH may result in cyanobacteria succeeding the green algae during summer and fall. Diatoms generally return in the fall, but cyanobacteria, greens, or diatoms may cause algae blooms following fall turnover when hypolimnetic nutrients are mixed throughout the water column. The general pattern of seasonal succession of phytoplankton is fairly constant from year to year. However, hydrologic variability, such as increased mixing and delay in the onset of stratification during cool, wet spring periods, can maintain diatoms longer in the spring and shift or modify the successional pattern of algae in reservoirs.

Phytoplankton grazers can reduce the abundance of algae and alter their successional patterns. Some phytoplankton species are consumed and assimilated more readily and are preferentially selected by consumers. Single-celled diatom and green algae species are readily consumed by zooplankton, while filamentous cyanobacteria are avoided by zooplankters. Altering the fish population can result in a change in the zooplankton population that can affect the phytoplankton population.

2.2.3.4 Organic Carbon and Detritus

Total organic carbon (TOC) is composed of dissolved organic carbon (DOC) and particulate organic carbon (POC). Detritus represents that portion of the POC that is nonliving. Nearly all the TOC of natural waters consists of DOC and detritus, or dead POC. The processes of decomposition and consumption of TOC are important in reservoirs and can have a significant affect on water quality.

DOC and POC are decomposed by microbial organisms. This decomposition exerts an oxygen demand that can remove dissolved oxygen from the water column. During stratification, the metalimnion and hypolimnion become relatively isolated from sources of dissolved oxygen, and depletion can occur through organic decomposition. There are two major sources of this organic matter: allochthonous (i.e., produced outside the reservoir and transported in) and autochthonous (i.e., produced within the reservoir). Allochthonous organic carbon in small streams may be relatively refractory since it consists of decaying terrestrial vegetation that has washed or fallen into the stream. Larger rivers, however, may contribute substantial quantities of riverine algae or periphyton that decompose rapidly and can exert a significant oxygen demand. Autochthonous sources include dead plankton settling from the mixed layers and macrophyte fragments and periphyton transported from the littoral zone. These sources are also rapidly decomposed.

POC and DOC absorbed onto sediment particles may serve as a major food source for aquatic organisms. The majority of the phytoplankton production enters the detritus food web with a minority being grazed by primary consumers (USACE, 1987). While autochthonous production is important in reservoirs, typically as much as three times the autochthonous production may be contributed by allochthonous material (USACE, 1987).

2.2.4 BOTTOM WITHDRAWAL RESERVOIRS

Bottom withdrawal structures are located near the deepest part of a reservoir. Bottom withdrawal removes hypolimnetic water and nutrients and may promote movement of interflows or underflow into the hypolimnion. They release coldwaters from the deep portion of the reservoir; however, these waters may be anoxic during periods of stratification. Bottom outlets can cause density interflows or underflows (e.g., flow laden with sediment or dissolved solids) through the reservoir and generally provide little or no direct control over release water quality.

The outlet works at Garrison Dam utilize a bottom withdrawal from Lake Sakakawea. The intake structure at Garrison Dam consists of 5 power tunnels and 3 regulating tunnels. An intake channel was excavated from the old Missouri River channel to the intake works during dam construction. The length of intake channel from the old Missouri River channel to the intake works is approximately 2 ½ miles. The bottom of the intake channel is at an elevation of 1670 ft-msl. The intake channel ends at the intake structure with trash racks that extend from elevation 1672 to 1775 ft-msl (i.e., the lowest elevation that water is drawn from Lake Sakakawea is 2 feet above the bottom of the lake). The gate openings for the 5 power unit tunnels extend from elevation 1672 to 1698 ft-msl, while the gate openings for the 3 regulating tunnels (i.e., flood control) extend from elevation 1672 to 1696.5 ft-msl. The maximum normal operating pool for Lake Sakakawea is 1850 ft-msl and the minimum multi-purpose pool elevation is 1775 ft-msl.

2.3 APPLICATION OF THE CE-QUAL-W2 WATER QUALITY MODEL TO THE MISSOURI RIVER MAINSTEM SYSTEM PROJECTS

Water quality data must be applied to understand and manage water resources effectively. Application of appropriate mathematical models promotes efficient and effective use of data. Models are powerful tools for guiding project operations, refining water quality sampling programs, planning project modifications, evaluating management scenarios, improving project benefits, and illuminating new or understanding complex phenomena. CE-QUAL-W2 is a "state-of-the-art" water quality model that can greatly facilitate addressing reservoir water quality management issues.

CE-QUAL-W2 is a water quality and hydrodynamic model in two dimensions (longitudinal and vertical) for rivers, estuaries, lakes, reservoirs, and river basin systems. CE-QUAL-W2 models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Version 1.0 of the model was developed by the Corps' Water Quality Modeling Group at the Waterways Experiment Station in the late 1980's. The current model release is Version 3.2 and is supported by the Corps' Engineer Research and Development Center (ERDC) and Portland State University.

2.3.1 PAST APPLICATION OF THE CE-QUAL-W2 MODEL

Version 2.0 of the CE-QUAL-W2 model was applied to four of the upper Mainstem System Projects in the early 1990's (i.e., Ft. Peck Lake, Lake Sakakawea, Lake Oahe, and Lake Francis Case). The application of the model was part of the supporting technical documentation of the Environmental Impact Statement (EIS) that was prepared for the Missouri River Master Water Control Manual Review and Update Study. The results of the model application were included as an Appendix to the Review and Update Study – "Volume 7B: Environmental Studies, Reservoir Fisheries, Appendix C – Coldwater Habitat Model, Temperature and Dissolved Oxygen Simulations for the Upper Missouri River Reservoirs" (Cole et. al., 1994). The report (Cole et. al, 1994) provided results of applying the model to the four reservoirs regarding the effects of operational changes on in-lake coldwater fish habitat. This early application of the model represents the best results that could be obtained based on the model version and water quality data available at that time, and provided predictive capability for two system operational variables of concern – end-of-month stages and monthly average releases.

Although application of the CE-QUAL-W2 (Version 2.0) model met its intended purpose at the time, a lack of available water data placed limitations on its full utilization. These limitations were discussed in the Master Water Control Review and Update Study report (Cole et. al, 1994). The following excerpts are taken from that report:

> *"Typically, dissolved oxygen (DO) is modeled along with a full suite of water quality variables including algal/nutrient interactions. Lack of available algal/nutrient data necessitated a different approach. DO was assumed to be a function of sediment and water column oxygen demands which were adjusted during calibration to reproduce the average DO depletion during summer stratification. The drawback to this approach is that operational changes which might affect algal/nutrient interactions cannot be predicted. Results from this study show only how physical factors relating to changes in reservoir stage and discharge affect DO."*

> *"As a result, model predictions during scenario runs represent only how physical factors affect DO and do not include the effects of reservoir operations on algal/nutrient dynamics and their effects on DO. To include algal/nutrient effects would require at least one year's*

worth of detailed algal/nutrient data for each reservoir that were not and could not be made available during the time frame of this study."

"Steps should be taken to obtain a suitable database that can be used to calibrate the entire suite of water quality algorithms in the model. It is almost a certainty that water quality issues will remain important in the future."

The current version of the CE-QUAL-W2 model (Version 3.2) has incorporated numerous enhancements over the Version 2.0 model that was applied to the four Mainstem System Projects in the early 1990's. These enhancements, among other things, include improvements to the numerical solution scheme, water quality algorithms, two-dimensional modeling of the waterbasin, code efficiencies, and user-model interface. Communication with the author of the past application of the Version 2.0 model to the Mainstem System Projects and current model support personnel indicated that the Omaha District should pursue implementing Version 3.2 of the model (personal communication, Thomas M. Cole, USACE/ERDC).

2.3.2 FUTURE APPLICATION OF THE CE-QUAL-W2 MODEL

As part of its Water Quality Management Program, the Omaha District has initiated the application of the CE-QUAL-W2 (Version 3.2) model to the Mainstem System Projects. The District is approaching the model application as an ongoing, iterative process. Data will be collected and the model run and continuously calibrated as new information is gathered. The goal is to have a fully functioning model in place for all the Mainstem System Projects that meets the uncertainty requirements of decision-makers.

The current plan for applying the model to a single project will encompass a 5-year period. During years 1 through 3 an intensive water quality survey will be conducted to collect the water quality data needed to fully calibrate the model. Application and calibration of the model will occur in years 4 and 5. Once the model has been calibrated and "finalized", it will be used to facilitate the development of a Project-Specific Water Quality Report and Water Quality Management Plan for the project. The current plan is to stagger the application of the model by annually beginning the application process at a different Mainstem System Project. The tentative order for applying the model to the Projects is: 1) Garrison Project, 2) Fort Peck Project, 3) Oahe Project, 4) Fort Randall Project, 5) Big Bend Project, and 6) Gavins Point Project. The 3-year intensive water quality survey was conducted at the Garrison Project during 2003 through 2005, and the application and calibration of the model to Lake Sakakawea is currently ongoing. Eventually it is hoped that the CE-QUAL-W2 models developed for each of the Projects can be linked and used to make integrated water quality management decisions throughout the Mainstem System.

2.3.3 CURRENT APPLICATION OF THE CE-QUAL-W2 MODEL TO LAKE SAKAKAWEA

The Garrison Project is the first Mainstem System Project where the Version 3.2 CE-QUAL-W2 model is being applied, and its application to Lake Sakakawea is currently ongoing. Current application efforts, among other things, have focused on modifying the earlier developed reservoir bathymetry files, refining the calibration of outflow water quality conditions, and activating the model's water quality algorithms. In the application of the Version 2.0 model to Lake Sakakawea in the early 1990's, the varying configuration of the reservoir bottom within 5,000 feet of Garrison Dam was not considered. The intake channel to the Garrison Dam outlet works, which was excavated when the dam was constructed and is now submerged, is within this area (see Section 2.2.4). Since water drawn into the outlet works must flow through the submerged intake channel, it's believed the configuration of the intake channel, and the resulting influence on flow dynamics, needs to be accounted for in the bathymetry file to allow the calibration and performance of the model to meet current expectations. Much more detailed outflow data, regarding monitored water quality conditions, currently exists to refine the calibration of the model. The water quality algorithms that describe the nutrient/algae/dissolved oxygen interactions are being calibrated. The goal is to have the model mechanistically determine in-lake dissolved oxygen levels, and to use the model's predictive capabilities to evaluate factors influencing the occurrence of dissolved oxygen in Lake Sakakawea. A Water Quality Special Report will be prepared at a future date describing the application and calibration of the CE-QUAL-W2 Version 3.2 model to Lake Sakakawea.

3 DATA COLLECTION METHODS

3.1 DATA COLLECTION DESIGN

3.1.1 MONITORING LOCATIONS

The Omaha District collected water quality data at 17 locations at the Garrison Project during the period 2003 through 2005. Of the 17 locations, 14 were located in Lake Sakakawea, 2 were located on the major tributary inflows to the lake (i.e., Missouri River and Little Missouri River), and 1 was located in the Garrison Dam powerhouse. Table 3.1 describes the monitoring locations in greater detail, and Figures 3.1 and 3.2 show their locations.

Table 3.1. Location and description of monitoring stations that were sampled by the Omaha District for water quality at the Garrison Project during the period 2003 through 2005.

Station Number	Station Alias	Name	Location	Station Type	Latitude	Longitude
GARNFMORRR1	NF1	Missouri River near Williston, ND	At US Hwy 85 bridge crossing	Inflow	-----	-----
GARNFLMOR1	NF2	Little Missouri River near Killdeer, ND	At ND Hwy 22 bridge crossing	Inflow	-----	-----
GARPP1	OF1	Garrison Powerhouse	In powerhouse – water drawn from raw water loop	Outflow	-----	-----
GARPPP1	P1	Garrison Powerhouse Penstock 1	In powerhouse – water drawn from penstock 1	Outflow	-----	-----
GARPPP2	P2	Garrison Powerhouse Penstock 2	In powerhouse – water drawn from penstock 2	Outflow	-----	-----
GARPPP3	P3	Garrison Powerhouse Penstock 3	In powerhouse – water drawn from penstock 3	Outflow	-----	-----
GARPPP4	P4	Garrison Powerhouse Penstock 4	In powerhouse – water drawn from penstock 4	Outflow	-----	-----
GARPPP5	P5	Garrison Powerhouse Penstock 5	In powerhouse – water drawn from penstock 5	Outflow	-----	-----
GARLK1390B1	IC1	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.50965	W101.43152
GARLK1390B2	IC2	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.51415	W101.42422
GARLK1390B3	IC3	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.51302	W101.41453
GARLK1390B4	IC4	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.51142	W101.40575
GARLK1390B5	IC5	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.50903	W101.39363
GARLK1390B6	IC6	Lake Sakakawea – Intake Channel	In-Lake, Intake Channel	Reservoir	N47.50910	W101.38323
GARLK1390A	L1	Lake Sakakawea – Government Bay	In-Lake, Deepwater	Reservoir	N47.51557	W101.37150
GARLK1399DW	L2	Lake Sakakawea – Douglas Bay	In-Lake, Deepwater	Reservoir	N47.55195	W101.51500
GARLK1412DW	L3	Lake Sakakawea – Beulah Bay	In-Lake, Deepwater	Reservoir	N47.52093	W101.76238
GARLK1428DW	L4	Lake Sakakawea – Indians Hills	In-Lake, Deepwater	Reservoir	N47.57782	W102.09877
GARLK1445DW	L5	Lake Sakakawea – Deepwater Bay	In-Lake, Deepwater	Reservoir	N47.71575	W102.25822
GARLK1454DW	L6	Lake Sakakawea – Independence Point	In-Lake, Deepwater	Reservoir	N47.77992	W102.36332
GARLK1481DW	L7	Lake Sakakawea – New Town	In-Lake, Deepwater	Reservoir	N47.98958	W102.56278
GARLK1493DW	L8	Lake Sakakawea – White Earth Bay	In-Lake, Deepwater	Reservoir	N48.10705	W102.73053

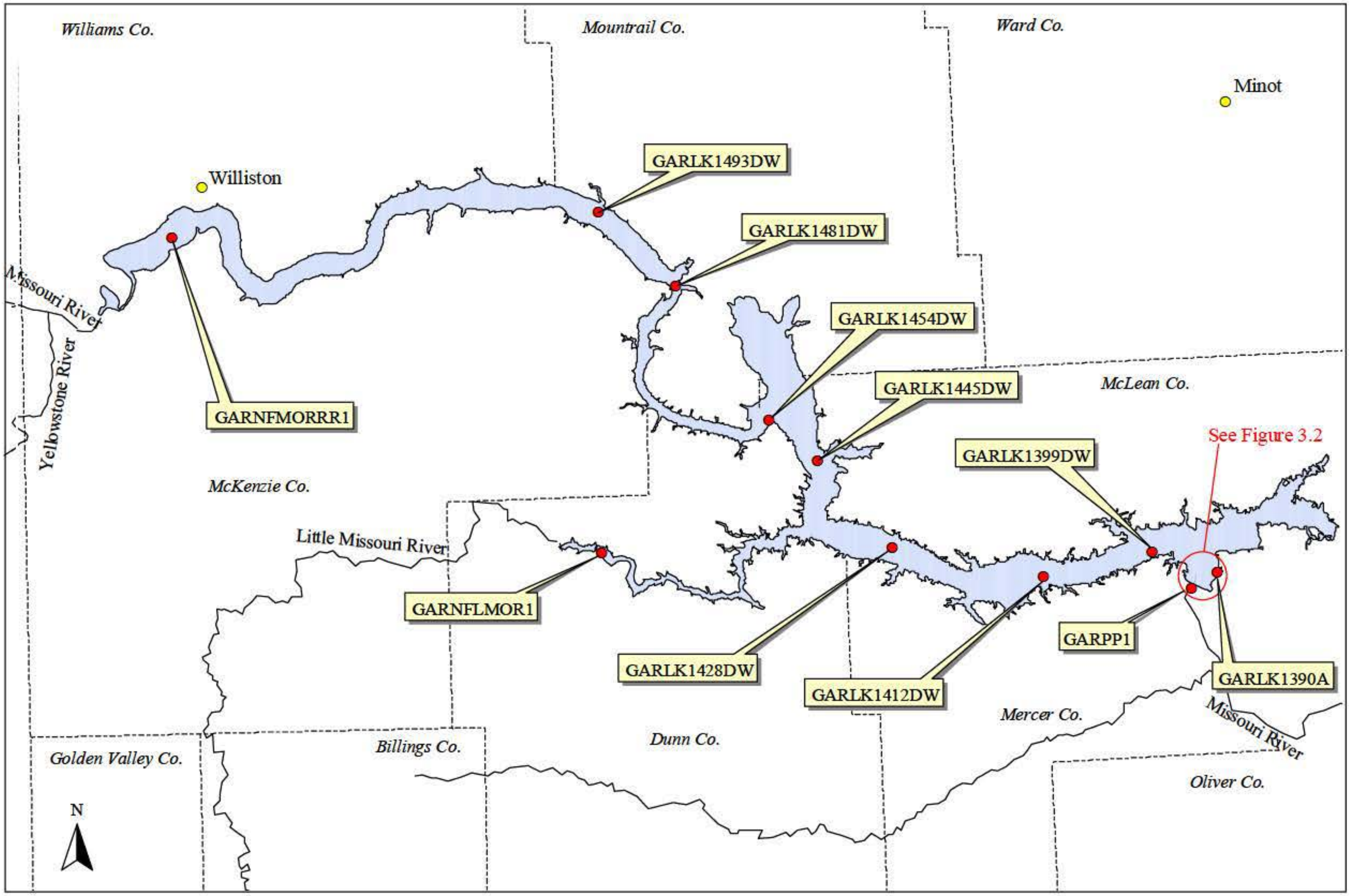


Figure 3.1. Location of sites where water quality monitoring was conducted by the Omaha District at the Garrison Project during the period 2003 through 2005.

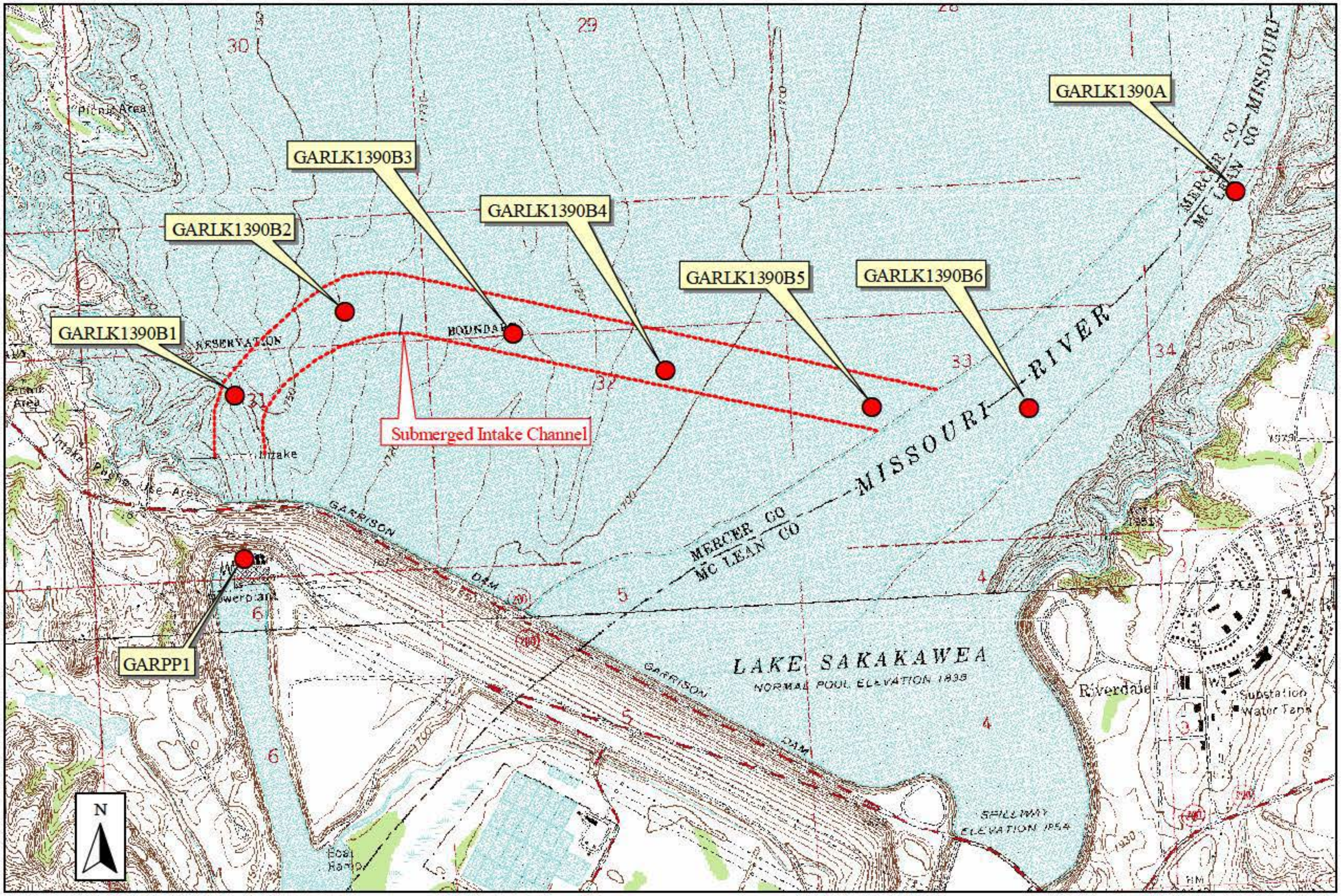


Figure 3.2 Location of sites where water quality monitoring was conducted by the Omaha District near the Garrison Dam during the 2005 Special Water Quality Study.

3.1.2 MONITORING STATION TYPES

The monitoring stations where water quality data were collected during the period 2003 through 2005 were categorized into three types: 1) in-lake, 2) inflow, and 3) outflow (Table 3.1). All the in-lake stations were meant to represent "deepwater" pelagic conditions, and were established at the deepest part of the lake with regards to the area being monitored. The in-lake stations were oriented along two longitudinal axes – old Missouri River channel and dam intake channel. Eight in-lake monitoring stations (i.e., L1 through L8) were approximately equally spaced along the longitudinal axis of Lake Sakakawea from near the dam to the upper reaches of the lake (Figure 3.1). These stations were located along the submerged old Missouri River channel with the farthermost of the eight stations separated by 103 miles. Depending on lake surface elevation, the eight stations are believed to be associated with the following lakes zones: Lacustrine Zone (L1, L2, L3), Zone of Transition (L4, L5, L6), and Riverine Zone (L7 and L8). The other six in-lake monitoring stations (i.e., IC1 through IC6) were equally spaced along the submerged intake channel near the Garrison Dam (Figure 3.2). The farthermost of these stations were separated by approximately 2½ miles. The two inflow stations were located on the Missouri River and Little Missouri River just upstream of their confluence with Lake Sakakawea (Figure 3.1). The single outflow station was located in the Garrison Dam powerhouse. Water quality data collected at this station consisted of monitoring the quality of the water being discharged through the dam's penstocks.

3.1.3 MEASUREMENTS, SAMPLE TYPES, AND COLLECTION FREQUENCY

3.1.3.1 <u>In-Lake Monitoring Stations</u>

3.1.3.1.1 Old Missouri River Channel

Monitoring at these eight stations (i.e., L1 through L8) consisted of field measurements and collection of discrete-depth "grab" samples for laboratory analysis. Field measurements were taken monthly to bi-weekly and grab samples were collected monthly during the period May through September. Up to four depth-discrete grab samples were collected at the sampled stations based on the presence of thermal stratification and field measurable chlorophyll *a*. The four depth-discrete samples that were collected included: 1) near-surface (i.e., ½ the measured Secchi depth), 2) near-bottom (i.e., within 2 meters of the lake bottom), 3) mid-metalimnion (i.e., middle of the metalimnion zone), and 4) maximum chlorophyll (i.e., depth of maximum field measured chlorophyll *a* in the epilimnion). These eight stations have also been monitored by the State of North Dakota over the past 10 years.

3.1.3.2 <u>Garrison Dam Intake Channel</u>

Monitoring at these six stations (i.e., IC1 through IC6) consisted of monthly depth-profile measurements taken from July through September during 2005.

3.1.3.3 <u>Inflow Monitoring Stations</u>

Monitoring at these two stations (i.e., NF1 and NF2) consisted of field measurements and collection of grab samples. A near-surface, mid-channel grab sample was collected at each site from the bridge. Monitoring on the Missouri River (site NF1) occurred monthly to biweekly during the period May through September in 2003, 2004, and 2005. Monitoring on the Little Missouri River (site NF2) was conducted monthly during the period June through September in 2003 and 2004.

3.1.3.4 <u>Outflow Monitoring Station</u>

Monitoring at the Garrison powerhouse consisted of hourly logging of water quality conditions and monthly collection of grab samples. Monitoring at this station (site OF1) occurred year-round. The hourly measurements logged included water temperature, dissolved oxygen, pH, and conductivity. During the period June 2003 through mid-July 2005, the water monitored was drawn from the "raw-water loop" within the powerhouse. The "raw-water loop" is an open ended loop that draws water from the dam's five individual penstocks for utilization within the powerhouse. After mid-July 2005, water was drawn from each of the five individual penstocks for monitoring.

3.1.4 PARAMETERS MEASURED AND ANALYZED

3.1.4.1 <u>Water Quality Parameters</u>

The water quality parameters that were measured and analyzed at the various monitoring stations are given in Table 3.2.

Table 3.2. Parameters measured and analyzed at the various monitoring stations.

Parameter	In-Lake		NF1 & NF2	OF1
	L1 – L8	IC1 – IC6		
Dissolved Solids, Total	✓		✓	✓
Organic Carbon, Total (TOC)	✓		✓	✓
Orthophosphorus, Dissolved	✓		✓	✓
Phosphorus, Total	✓		✓	✓
Dissolved Phosphorus, Total	✓		✓	✓
Nitrate-Nitrite as N, Total	✓		✓	✓
Ammonia as N, Total	✓		✓	✓
Kjeldahl Nitrogen, Total	✓		✓	✓
Suspended Solids, Total	✓		✓	✓
Alkalinity	✓		✓	✓
Sulfate	✓		✓	✓
Chlorophyll a	✓			
Phytoplankton Biomass and Taxa Identification	✓			
Silca, Total and Dissolved	✓		✓	✓
Iron, Total and Dissolved	✓		✓	✓
Manganese, Total and Dissolved	✓		✓	✓
Metals and Hardness	✓			
Pesticide Scan	✓			
Microcystins	✓			
Secchi Depth/Transparency	✓			
Depth-Profile	✓**	✓**	✓**	
Continuous Monitoring ("Hydrolab")				✓***

Note: Not all parameters were monitored at all the sites indicated.

** Profile to include: water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, ORP, turbidity, and chlorophyll *a*. Measurements taken at 1-meter intervals from the lake surface to the bottom.

*** Continuous monitored parameters include temperature, dissolved oxygen (mg/l and % saturation) pH, and conductivity.

3.1.4.2 <u>Explanatory Variables</u>

Explanatory variables that were quantified included inflow discharge, outflow discharge, and lake pool elevation. Inflow discharge at station NF1 was determined by adding recorded discharge at the USGS gage (06185500) on the Missouri River at Culbertson, MT and the USGS gage (06329500) on the Yellowstone River at Sidney, MT. Inflow discharge at station NF2 was determined from the USGS gage (06337000) on the Little Missouri River near Walford City, ND. Outflow discharge from Garrison Dam and the pool elevation of Lake Sakakawea were obtained from Garrison Project records.

3.2 WATER QUALITY MEASUREMENT AND SAMPLING METHODS

3.2.1 FIELD MEASUREMENTS

Depth-profile and surface measurements for water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, Oxidation-Reduction potential (ORP), turbidity, and chlorophyll *a* were taken using a "Hydrolab 4" equipped with a DataSonde 4a probe and Surveyor 4 data logger. Profile measurements were taken at 1-meter intervals. The Hydrolab was operated as specified in the USACE – Water Quality Unit's Standard Operating Procedure (SOP) Number WQ-21201, "Using a Hydrolab 4 & 4a to Directly Measure Water Quality" (USACE, 2004b). Secchi transparency was measured in accordance with the USACE – Water Quality Unit's SOP Number WQ-21202, "Determining Secchi Depth" (USACE, 2004c).

3.2.2 WATER QUALITY SAMPLE COLLECTION AND ANALYSIS

All water quality samples were collected in accordance with the USACE – Water Quality Unit's SOP Number WQ-21101, "Collection of Surface Water Samples" (USACE, 2003). Surface grab samples were collected by dipping a rinsed plastic churn bucket just below the surface (i.e., approximately 6 inches below the surface). Depth-discrete grab samples were collected with a Kemmerer sampler that was lowered to the desired sampling depth, triggered, and retrieved to the boat.

3.3 ANALYTICAL METHODS

All collected water quality samples were delivered to the Corps' Engineer Research and Development Center (ERDC), Environmental Chemistry Branch Laboratory in Omaha, Nebraska for laboratory analysis. The analytical methods, detection limits, and reporting limits for the analysis of the collected water quality samples are given in Table 3.3. Analysis of the collected plankton samples was done by an outside laboratory under contract to the ERDC Omaha Laboratory.

Table 3.3. Methods, detection limits, and reporting limits for analyses conducted by the Corps' ECB Laboratory.

Analyte	Method	Detection Limit	Reporting Limit
Alkalinity, Total	EPA - 310.2	7 mg/l	20 mg/l
Nitrate/Nitrite, Total as N	EPA - 300.0 / 353.2	0.02 mg/l	0.1 mg/l
Ammonia, Total as N	EPA - 350.1	0.01 mg/l	0.1 mg/l
Kjeldahl Nitrogen, Total as N	EPA - 351.2	0.1 mg/l	0.2 mg/l
Phosphorus, Total as P	EPA - 300.0 / 365.4	0.01 mg/l	0.02 mg/l
Phosphorus, Total Dissolved	EPA - 365.4	0.01 mg/l	0.02 mg/l
Orthophosphorus	EPA - 365.1	0.01 mg/l	0.03 mg/l
Sulfate, Total	EPA - 300.0 / 375.2	0.01 mg/l / 6 mg/l	0.1 mg/l / 20 mg/l
Dissolved Solids, Total	EPA - 160.1	5 mg/l	10 mg/l
Suspended Solids, Total	EPA - 160.2	4 mg/l	10 mg/l
Organic Carbon, Total (TOC)	EPA - 9060	0.05 mg/l	0.25 mg/l
Organic Carbon, Dissolved (DOC)	EPA - 9060	0.05 mg/l	0.25 mg/l
Dissolved Metals:	EPA - 6010B		
Antimony		6 ug/l	20 ug/l
Arsenic		3 ug/l	15 ug/l
Beryllium		0.5 ug/l	2 ug/l
Cadmium		0.5 ug/l	2.5 ug/l
Calcium		100 ug/l	300 ug/l
Chromium III		2 ug/l	10 ug/l
Copper		2 ug/l	10 ug/l
Nickel		3 ug/l	10 ug/l
Lead		2 ug/l	10 ug/l
Magnesium		40 ug/l	120 ug/l
Silver		1 ug/l	5 ug/l
Thallium		6 ug/l	30 ug/l
Zinc		3 ug/l	10 ug/l
Mercury, dissolved and total	EPA - 7470A	0.02 ug/l	0.1 ug/l
Iron and Manganese, total and dissolved	EPA - 6010B	40 ug/l	120 ug/l
Selenium, total	EPA - 6010B	4 ug/l	20 ug/l
Silica, Total and Dissolved	EPA - 6010B	20 ug/l	100 ug/l
Chlorophyll *a*	SM - 10200H2	1 ug/l	3 ug/l
Pesticide scan*:	EPA - 507	0.05 ug/l	0.1 ug/l
Immunoassay – Herbicides (Alachlor, Atrazine, Metolachlor)	Rapid Assay	0.05ug/l	0.1 ug/l
Immunoassay – Microcystins	Rapid Assay	0.2 ug/l	1 ug/l

* Pesticide scan included: Acetochlor, Alachlor, Atrazine, Benfluralin, Butylate, Chlorpyrifos, Cyanazine, Cycloate, EPTC, Hexazinone, Isopropalin, Metolachlor, Metribuzin, Molinate, Oxadiazon, Oxyfluorfen, Pebulate, Pendimethalin, Profluralin, Prometon, Propachlor, Propazine, Simazine, Trifluralin, Vernolate.

4 DATA ASSESSMENT METHODS

4.1 EXISTING WATER QUALITY (2003 THROUGH 2005)

4.1.1 GENERAL WATER QUALITY CONDITIONS

Statistical analyses were performed on the water quality monitoring data collected at in-lake, inflow, and outflow sites during the period 2003 through 2005. Descriptive statistics (i.e., mean, median, minimum, maximum) were calculated to describe central tendencies and the range of observations. Where appropriate, monitoring results were compared to defined North Dakota water quality standards criteria.

Spatial variation of selected water quality parameters in Lake Sakakawea was evaluated. Longitudinal contour plots were constructed for water temperature, dissolved oxygen, and turbidity to display likely conditions in Lake Sakakawea from its upper reaches to Garrison Dam. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" included in the "Data Management and Analysis System for Lakes, Estuaries, and Rivers" (DASLER-X) software developed by HydroGeoLogic, Inc. (Hydrogeologic Inc., 2005). Secchi depth measurements collected along Lake Sakakawea were evaluated and are displayed using a box plot. The variation of nutrient concentrations with depth were evaluated at site L1 by comparing near-surface, mid-depth, and near-bottom collected samples.

Temporal changes in water quality conditions measured in the deepwater area near Garrison Dam were evaluated. Near-bottom water temperature and dissolved oxygen concentrations measured at site L1 were plotted by year for comparison.

The phytoplankton community was evaluated based on collected grab samples. A listing of taxa occurrence, to the species level where possible, was compiled. The frequency of occurrence of a taxon was determined based on the number of samples in which the taxon was present out of the 45 total phytoplankton samples collected. Frequency of occurrence was quantified as follows: Rare – taxon present in 1 to 4 samples, Occasional – taxon present in 5 to 10 samples, and Common – taxon present in more than 10 samples. The relative abundance of a taxon determined based on the taxon biovolume as a percent of the total sample biovolume. Relative abundance was quantified as follows: Very Low – taxon biovolume < 1%, Low – taxon biovolum 1 to 5%, Medium – taxon biovolume 5 to 10%, and High – taxon biovolume > 10%.

4.1.2 LAKE TROPHIC STATUS

Reservoirs are commonly classified or grouped by trophic or nutrient status. The natural progression of lakes through time is from an oligotrophic (i.e., low nutrient/low productivity) through a mesotrophic (i.e., intermediate nutrient/intermediate productivity) to a eutrophic (i.e., high nutrient/high productivity) condition. The prefixes "ultra" and "hyper" are sometimes added to oligotrophic or eutrophic, respectively, as additional degrees of trophic status. The tendency toward the eutrophic, or nutrient-rich, status is common to all impounded waters. The eutrophication or enrichment process can adversely impact water quality conditions in lakes (e.g., increased occurrence of algal blooms, noxious odors, and fish kills; reduced water clarity; reduced hypolimnetic dissolved oxygen concentrations; etc.). Eutrophication of lakes can be accelerated by nutrient additions through cultural activities (e.g., point-source discharges and nonpoint sources such as runoff from cropland, livestock facilities, urban areas, etc.).

A Trophic State Index (TSI) can be calculated as described by Carlson (1977). TSI values are determined from Secchi disk transparency, total phosphorus, and chlorophyll *a* measurements. Values for these three parameters are converted to an index number ranging from 0 to 100 according to the following equations:

TSI(Secchi Depth) = TSI(SD) = 10[6 - (ln SD/ln 2)]
TSI(Chlorophyll *a*) = TSI(Chl) = 10[6 - ((2.04-0.68 ln Chl)/ln 2)]
TSI(Total Phosphorus) = TSI(TP) = 10[6 – (ln (48/TP)/ln 2)]

Accurate TSI values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass. Accurate TSI values from Secchi disk transparency depend on the assumption that water clarity is primarily limited by phytoplankton biomass. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake's trophic condition during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake's epilimnion during summer stratification provide the best agreement between all of the index parameters and facilitate comparisons between lakes. Care should be taken if a TSI average score is calculated from the three individual parameter TSI values. If significant differences exist between parameter TSI values, the calculated average value may not be indicative of the trophic condition estimated by the individual parameter values. With this in mind, a TSI average value [TSI(Avg)] calculated as the average of the three individually determined TSI values [i.e., TSI(SD), TSI(Chl), and TSI(TP)] is used by the Omaha District as an overall indicator of a lake's trophic state. The Omaha District uses the criteria defined in Table 4.1 for determining lake trophic status from TSI values.

Table 4.1. Lake trophic status based on calculated Trophic State Index (TSI) values.

TSI	Trophic Condition
0-35	Oligotrophic
36-50	Mesotrophic
51-55	Moderately Eutrophic
56-65	Eutrophic
66-100	Hypereutrophic

In addition to classifying lakes, the TSI can serve as an internal check on the assumptions about the relationships among various components of a lake's ecosystem. Carlson states that that the three TSI parameters, when transformed to the trophic scale, should have similar values. Any divergence from this value by one or more of the parameters may provide insights into a lake's water quality dynamics (e.g., is the lake phosphorus limited, is water clarity limited by algae or nonalgal particulate matter, etc.)

Existing trophic conditions were assessed for Lake Sakakawea based on the monitoring conducted during the 2003 through 2005 period. The data evaluated consisted of Secchi depth measurements and total phosphorus and chlorophyll *a* analytical results obtained at sites L1 through L8. TSI values were calculated and compared to the above criteria.

4.1.3 TIME-SERIES PLOTS OF FLOW, WATER TEMPERATURE, AND DISSOLVED OXYGEN OF WATER DISCHARGED THROUGH GARRISON DAM

Time series plots were prepared for conditions measured at the Garrison Dam powerhouse during the 2003 through 2005 period. Discharge was plotted with hourly temperature and dissolved oxygen measurements. Plots were for measurements taken from the "raw water" loop and individual penstocks.

4.2 ESTIMATING THE OCCURRENCE OF COLDWATER HABITATS IN LAKE SAKAKAWEA

4.2.1 COLDWATER HABITAT CRITERIA – WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen levels are primary water quality factors that determine the suitability of water for coldwater aquatic life. Water quality standards for the protection of aquatic life (i.e., water temperature and dissolved oxygen criteria) usually include different levels of protection based on habitat types, life stages (i.e., eggs, fry, juvenile, and adults), and acute and chronic effects. Determining the appropriate water quality criteria needed to maintain coldwater habitat for the protection of coldwater aquatic life is complicated by the "gradient effect" water quality conditions have on aquatic life. Water quality standards criteria for the protection of coldwater aquatic life, recommended by the U.S. Environmental Protection Agency (EPA) and adopted by many States, account for this gradient effect by defining different coldwater aquatic life use classes and incorporating criteria factors that consider magnitude, duration, and frequency of occurrence. The State of North Dakota has not specifically promulgated numeric temperature criteria for the protection of coldwater aquatic life in Lake Sakakawea in the State's water quality standards. However, as part of the State's fishery management program, a water temperature of ≤ 15° C has been identified as optimal for managing the coldwater fishery habitat of the lake. The State's water quality standards specify a dissolved oxygen numeric criteria of ≥ 5 mg/l for the protection of the aquatic life of Lake Sakakawea. The State of South Dakota has assigned a use of "Coldwater Permanent Fish Life Propagation" to Lake Oahe, which has a fishery similar to Lake Sakakawea's (i.e., "two-story" fishery with rainbow smelt as a primary forage base). For the protection of this use, the State of South Dakota has promulgated the following numeric water quality standards criteria for water temperature and dissolved oxygen: water temperature ≤ 65°F (18.3°C), and dissolved oxygen ≥ 6.0 mg/l (≥ 7.0 mg/l in spawning areas during the spawning season).

The State of North Dakota has identified the volume of optimal coldwater habitat it feels is necessary to protect the existing "two-story" fishery in Lake Sakakawea. The State feels a volume of 800,000 acre-feet is needed to fully protect the fishery, and severe impairment to the fishery will be incurred if the optimal coldwater habitat volume goes below 200,000 acre-feet. The State has projected that a surface elevation of about 1825 feet-msl, when thermal stratification becomes established in late spring, is needed to ensure at least 200,000 acre-feet of optimal coldwater habitat remain in the lake through fall turnover. This assumes that Garrison Dam is operated as it has been in the past, and does not consider the implementation of any new water quality management measures to protect coldwater habitat.

4.2.2 DEFINITION OF COLDWATER HABITAT TYPES AND CRITERIA FOR LAKE SAKAKAWEA

For evaluating the coldwater habitat present in Lake Sakakawea, two types of coldwater habitat were defined for use in this report based on water temperature and dissolved oxygen concentrations (Table 4.2). Optimal coldwater habitat is defined as water having a temperature of ≤ 15°C and a dissolved oxygen concentration of ≥ 5.0 mg/l. Marginal coldwater habitat is defined as water having a temperature of > 15°C and ≤ 18.3°C and a dissolved oxygen concentration of ≥ 5.0 mg/l. Defining different classes of coldwater habitat in this manner is an attempt to account for the gradient effect water temperature and dissolved oxygen may have on the coldwater aquatic life of Lake Sakakawea. Exposure of coldwater aquatic life to water temperatures > 15°C and ≤ 18.3°C and dissolved oxygen levels ≥ 5.0 mg/l may not support optimal growth, but may be protective depending on temporal occurrence (i.e., sensitive life stages not present), frequency of occurrence, and duration. Water temperatures > 15°C and ≤ 18.3°C are not believed directly detrimental to Chinook salmon, but there may be a concern regarding rainbow smelt which may be less tolerant to warmer water temperatures.

Table 4.2. Coldwater habitat types and associated water quality criteria.

Coldwater Habitat Type	Water Temperature Criteria	Dissolved Oxygen Criteria
Optimal	≤ 15°C	≥ 5.0 mg/l
Marginal	> 15°C and ≤ 18.3°C	≥ 5.0 mg/l

4.2.3 VOLUME ESTIMATION OF COLDWATER HABITATS IN LAKE SAKAKAWEA

Measured water temperature and dissolved oxygen concentration depth-profiles were used to estimate the volume of coldwater habitat in Lake Sakakawea. The volume estimates were based on the lake elevation and lake volume relationships defined by Houston Engineering in its Lake Sakakawea database for the report "Lake Sakakawea Analysis of Cold Water Habitat" (Houston Engineering, 2003). Table 4.3 shows these defined lake elevation and lake volume relationships. For estimating lake volumes, Houston Engineering divided Lake Sakakawea into eight regions that corresponded to water quality monitoring sites sampled by the State of North Dakota. Monitoring stations L1 through L8 were located at the same locations as these eight State water quality monitoring sites. Water temperature and dissolved oxygen concentration depth-profiles measured at monitoring stations L1 through L8 were compared to Table 4.3, and linear interpolation was used to estimate the volume of water in that lake region that met the defined optimal and marginal coldwater habitat criteria defined in Table 4.2.

4.3 EVALUATION OF SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

The potential impacts implementation of the short-term water quality management measures had on water quality conditions at Lake Sakakawea were evaluated by comparing conditions in modified penstocks to conditions in unmodified penstocks. Also, water quality conditions of water discharged through Garrison Dam in 2005 under the influence of implemented water quality management measures were compared to similar time periods in 2003 and 2004.

Table 4.3. Estimation of "regional" lake volumes (acre-feet) based on lake elevation.

Note: Relationship of lake elevation and regional lake volumes taken from database developed by Houston Engineering for North Dakota Department of Health.

Lake Elevation	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Sum Volume*	Corps Volume**
1830	1,545,259	2,921,784	2,635,670	2,119,225	1,920,375	2,039,085	1,491,071	1,274,898	15,947,367	15,916,490
1825	1,445,957	2,760,957	2,478,247	1,990,392	1,760,489	1,811,835	1,346,625	1,028,165	14,622,667	14,556,980
1820	1,346,715	2,600,194	2,320,824	1,861,921	1,601,029	1,585,247	1,206,457	783,903	13,306,290	13,275,410
1815	1,257,977	2,447,793	2,170,603	1,738,520	1,460,038	1,387,567	1,072,314	590,600	12,125,412	12,061,430
1810	1,169,300	2,295,457	2,020,382	1,615,480	1,319,474	1,190,549	942,448	399,768	10,952,858	10,921,980
1805	1,088,132	2,150,599	1,877,066	1,498,908	1,190,722	1,027,616	817,445	277,066	9,927,554	9,861,138
1800	1,007,024	2,005,805	1,733,749	1,382,698	1,061,969	865,345	696,719	154,786	8,908,095	8,877,219
1795	933,602	1,868,475	1,597,995	1,271,282	947,783	740,684	580,709	95,624	8,036,154	7,973,682
1790	860,240	1,731,209	1,462,241	1,160,228	833,596	616,686	468,977	36,883	7,170,060	7,139,184
1785	794,233	1,601,471	1,335,122	1,054,070	730,733	519,437	365,908	19,938	6,420,912	6,364,791
1780	728,287	1,471,798	1,208,002	948,273	627,870	422,850	267,117	3,415	5,677,612	5,646,736
1775	668,764	1,349,169	1,090,660	846,869	536,898	343,400	193,565	1,708	5,031,033	4,979,890
1770	609,302	1,226,605	973,317	745,827	445,925	264,613	124,291	407	4,390,287	4,359,411
1765	554,765	1,110,776	866,566	648,626	367,147	201,067	77,673	0	3,826,620	3,777,482
1760	500,288	995,012	759,815	551,787	288,368	138,183	35,333		3,268,786	3,237,910
1755	450,775	887,219	663,310	457,965	220,307	94,002	20,398		2,793,976	2,742,427
1750	401,323	779,491	566,804	364,505	152,246	50,485	5,462		2,320,316	2,289,440
1745	355,995	681,007	480,263	276,425	102,551	30,153	2,916		1,929,310	1,877,090
1740	310,728	582,588	393,722	188,707	52,856	9,820	369		1,538,790	1,507,914
1735	270,330	493,661	314,146	124,792	28,316	5,580	185		1,237,010	1,183,310
1730	229,992	404,798	234,569	61,238	3,776	1,340	0		935,713	904,837
1725	193,916	326,757	164,670	34,361	1,888	670			722,262	677,548
1720	157,901	248,781	94,771	7,845	0	0			509,298	492,365
1715	126,261	184,928	55,661	4,608					371,458	342,914
1710	94,682	121,137	16,550	1,733					234,102	226,141
1705	67,725	78,318	8,877	867					155,787	137,755
1700	40,828	35,561	1,203	0					77,592	75,086
1695	26,067	19,974	602						46,643	36,173
1690	11,345	4,449	0						15,794	14,592
1685	6,789	2,456							9,245	4,747
1680	2,271	526							2,797	2,194
1675	1,136	263							1,399	282
1670	39	63							102	43

* Total lake volume based on summing regional lake volumes determined by Houston Engineering relationship.

** Total lake volume from Corps Area-Capacity Tables based on 1988 survey.

5 LAKE SAKAKAWEA WATER QUALITY CONDITIONS

5.1 EXISTING WATER QUALITY CONDITIONS – 2003 THROUGH 2005

5.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

5.1.1.1 In-Lake Monitoring Stations

Tables 5.1 through 5.9 summarize the water quality conditions that were monitored in Lake Sakakawea during 2003 through 2005 at monitoring locations L1, L2, L3, L4, L5, L6, L7, and L8. These results indicate no major water quality concerns other than water temperature and dissolved oxygen for the support of coldwater habitat.

5.1.1.2 Inflow Monitoring Stations

Table 5.10 summarizes the water quality conditions that were monitored in the Missouri River near Williston, North Dakota (Site NF1) during the period 2003 through 2005. Table 5.11 summarizes the water quality conditions that were monitored in the Little Missouri River near Killdeer, North Dakota (Site NF2) during the same period. Table 5.11 indicates the general poor water quality conditions that occur in the Little Missouri River; however, it is noted that the inflow volume is relatively minor compared to the inflow from the Missouri River.

5.1.2 WATER TEMPERATURE

5.1.2.1 Annual Temperature Regime

The water temperature regime of Lake Sakakawea can be described by an annual cycle consisting of eight thermal periods: 1) winter ice cover, 2) spring turnover, 3) spring isothermal lake conditions, 4) late-spring/early-summer lake warming, 5) mid-summer maximum thermal lake stratification, 6) late-summer/early-fall lake cooling, 7) fall turnover, and 8) fall isothermal lake conditions leading to winter ice cover. During the winter ice cover period, Lake Sakakawea will be inversely stratified from the surface to the bottom as the more dense water (i.e., 4°C) settles to the bottom. When the ice cover melts in the spring, the lake will become isothermal at about 4°C and complete mixing of the lake volume will occur as spring turnover takes place. As the lake gradually warms in the spring, isothermal conditions (>4°C) will occur as long as sufficient energy is present to completely mix the lake water column. As the lake continues to warm in late spring and early summer, thermal stratification will occur, and the hypolimnion will become established. At some point in mid-summer, the lake will reach maximum thermal stratification (i.e., maximum temperature difference between water at the lake surface and lake bottom), and a distinct thermocline will be present. As the lake begins to cool in late summer, the epilimnion will expand downward, pushing the thermocline deeper, and the hypolimnetic volume of colder water will decrease. The lake will continue to cool until the lake becomes isothermal and mixing occurs through the entire water column and fall turnover occurs. As the lake continues to cool, temperatures will remain relatively isothermal until the lake cools to 4°C. Ice cover will then be established, and the annual thermal cycle of Lake Sakakawea will be completed.

Table 5.1. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near Government Bay at monitoring station GARLK1390A (L1) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	769	14.0	14.3	6.2	22.3	≤ 29.4[1] ≤ 18 3[1] ≤ 15.0[1]	0 146 351	0% 19% 46%
Dissolved Oxygen (mg/l)	0.1	769	8.2	8.1	3.9	11.7	≥ 5.0	19	3%
Dissolved Oxygen (% Sat.)	0.1	769	82.6	87.5	39.8	110.8	-----	-----	-----
Specific Conductance (umho/cm)	1	769	590	599	487	636	-----	-----	-----
pH (S.U.)	0.1	769	8.1	8.1	7.1	8.9	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	769	5.5	3.3	0.1	41.9	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	769	396	390	264	527	-----	-----	-----
Secchi Depth (in)	1	18	129	120	54	228	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	18	1819.1	1817.4	1807.3	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	33	170	170	161	181	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	35	0.08	0.07	0.03	0.18	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	35	0.24	0.14	0.01	1.2	4.6[2,3] 2.0[2,4]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	35	0.5	0.3	0.1	1.6	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	35	0.05	0.03	n.d.	0.41	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	35	-----	0.03	n.d.	0.08	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	35	-----	n.d.	n.d.	0.11	-----	-----	-----
Sulfate (mg/l)	0.1	31	167	164	153	188	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	22	428	419	363	572	-----	-----	-----
Suspended Solids, Total (mg/l)	4	35	-----	n.d.	n.d.	11	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	29	2.9	2.9	2.7	3.4	-----	-----	-----
Iron, Total (ug/l)	40	16	137	129	40	305	-----	-----	-----
Iron, Dissolved (ug/l)	40	16	-----	n.d.	n.d.	60	-----	-----	-----
Manganese, Total (ug/l)	1	19	-----	7	n.d.	22	-----	-----	-----
Manganese, Dissolved (ug.l)	1	15	-----	1	n.d.	6	-----	-----	-----
Silica, Total (ug/l)	20	14	2,978	2,967	2,438	3,343	-----	-----	-----
Silica, Dissolved (ug/l)	20	5	2,587	2,653	2,273	2,692	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	11	-----	1	n.d.	3	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	417	-----	n.d.	n.d.	7	-----	-----	-----
Alachlor (ug/l)	0.05	9	-----	n.d.	n.d.	n.d.	≤2	0	0%
Atrazine, Total (ug/l)	0.05	9	-----	n.d.	n.d.	0.13	≤3	0	0%
Metolachlor (ug/l)	0.05	9	-----	n.d.	n.d.	0.06	≤40	0	0%
Microcystins (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** [1] Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

[2] Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 14.3; respectively.

[3] Acute criterion for aquatic life.

[4] Chronic criterion for aquatic life.

Table 5.2. Summary of annual (May and August) water quality conditions monitored in Lake Sakakawea near Government Bay at monitoring station GARLK1390A (L1) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Hardness, Dissolved (mg/l)	0.4	4	211	211	207	215	-----	-----	-----
Antimony, Dissolved (ug/l)	20	2	-----	n.d.	n.d.	n.d.	6(3)	****	-----
Arsenic, Dissolved (ug/l)	3	4	-----	n.d.	n.d.	n.d.	340(1) 150(2) 50(3)	**** **** ****	----- ----- -----
Beryllium, Dissolved (ug/l)	4	2	-----	n.d.	n.d.	n.d.	4(3)	****	-----
Cadmium, Dissolved (ug/l)	0.5	4	-----	n.d.	n.d.	n.d.	10.5(1) 4.4(2) 5(3)	**** **** ****	----- ----- -----
Chromium, Dissolved (ug/l)	10	4	-----	n.d.	n.d.	34	3,323(1) 159(2) 100(3)	**** **** ****	----- ----- -----
Copper, Dissolved (ug/l)	2	4	-----	n.d.	n.d.	n.d.	29.3(1) 17.7(2) 1,000(3)	**** **** ****	----- ----- -----
Lead, Dissolved (ug/l)	2	4	-----	n.d.	n.d.	n.d.	211(1) 8.2(2) 15(3)	**** **** ****	----- ----- -----
Mercury, Total (ug/l)	0.02	4	-----	n.d.	n.d.	n.d.	1.7(1) 0.91(2) 0.05(3)	0 0 0	0% 0% 0%
Nickel, Dissolved (ug/l)	3	4	-----	n.d.	n.d.	17.	882(1) 98(2) 100(3)	**** **** ****	----- ----- -----
Selenium, Total (ug/l)	4	4	-----	n.d.	n.d.	n.d.	20(1) 5(2) 50(3)	0 0 0	0% 0% 0%
Silver, Dissolved (ug/l)	1	4	-----	n.d.	n.d.	n.d.	14.7(1)	****	-----
Zinc, Dissolved (ug/l)	3	4	-----	n.d.	n.d.	n.d.	226(1,2) 9,100(3)	**** ****	----- -----
Pesticide Scan (ug/l)*****	0.05	2	-----	n.d.	n.d.	n.d.	******	0	0%

n.d. = Not detected.

* Pesticide scan run on May near-surface samples and metals analyses run on August near-surface samples.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.

*** (1) Acute criterion for aquatic life. (Note: Several metals acute criteria for aquatic life are hardness based – criteria listed are based on a median hardness value of 211.)

(2) Chronic criterion for aquatic life. (Note: Several metal chronic criteria for aquatic life are hardness based – criteria listed are based on a median hardness value of 211.)

(3) Human health criterion for surface waters.

**** North Dakota's WQS criteria for metals are based on total recoverable. Most analyzed metal concentrations were dissolved and not directly comparable to WQS criteria. WQS criteria shown for comparison only.

***** The pesticide scan includes: acetochlor, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

****** Some pesticides do not have water quality standards criteria defined, and for those pesticides that have criteria, the criteria vary.

Table 5.3. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near Douglas Bay at monitoring station GARLK1399DW (L2) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	563	15.2	16.3	7.0	22.1	≤ 29.4[1] ≤ 18 3[1] ≤ 15.0[1]	0 101 310	0% 18% 55%
Dissolved Oxygen (mg/l)	0.1	563	7.7	7.9	3.6	9.6	≥ 5.0	34	6%
Dissolved Oxygen (% Sat.)	0.1	563	80.8	86.5	37.6	110.0	-----	-----	-----
Specific Conductance (umho/cm)	1	563	591	603	485	633	-----	-----	-----
pH (S.U.)	0.1	563	8.0	8.1	7.1	8.6	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	563	4.5	3.4	0.0	35.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	563	407	400	324	514	-----	-----	-----
Secchi Depth (in)	1	13	127	120	60	180	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	14	1820.6	1821.8	1813.4	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	9	161	161	157	165	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	9	0.12	0.10	0.07	0.19	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	6	0.54	0.40	0.37	1.3	4.6[2,3] 1.8[2,4]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	6	0.76	0.64	0.52	1.50	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	9	0.04	0.03	0.02	0.08	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	8	0.02	0.02	0.01	0.04	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	9	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate (mg/l)	0.1	9	164	159	145	188	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	9	370	381	276	444	-----	-----	-----
Suspended Solids, Total (mg/l)	4	9	-----	n.d.	n.d.	n.d.	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	9	3.1	3.1	2.7	3.5	-----	-----	-----
Iron, Total (ug/l)	40	2	149	149	78	219	-----	-----	-----
Iron, Dissolved (ug/l)	40	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/l)	1	2	15.3	15.3	7.6	23.0	-----	-----	-----
Manganese, Dissolved (ug.l)	1	2	2.8	2.8	1.5	4.1	-----	-----	-----
Silica, Total (ug/l)	20	8	3,136	3,151	2,749	3,806	-----	-----	-----
Silica, Dissolved (ug/l)	20	8	3,083	3,127	2,813	3,426	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	4	1.5	1.5	1	2	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	232	-----	n.d.	n.d.	11	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 16.3; respectively .

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.4. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near Beulah Bay at monitoring station GARLK1412DW (L3) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	619	15.6	16.7	7.0	22.1	≤ 29.4[1] ≤ 18 3[1] ≤ 15.0[1]	0 147 364	0% 24% 59%
Dissolved Oxygen (mg/l)	0.1	619	7.7	7.9	3.2	9.7	≥ 5.0	40	7%
Dissolved Oxygen (% Sat.)	0.1	619	81.4	86.2	33.6	108.8	-----	-----	-----
Specific Conductance (umho/cm)	1	619	586	590	458	628	-----	-----	-----
pH (S.U.)	0.1	619	8.1	8.1	6.9	9.0	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	619	6.2	3.7	0.0	93.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	619	400	398	265	520	-----	-----	-----
Secchi Depth (in)	1	17	111	108	60	150	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	17	1819.7	1817.6	1812.6	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	31	168	170	155	181	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	31	0.09	0.09	n.d.	0.22	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	31	0.25	0.12	0.02	1.20	4.6[2,3] 1.8[2,4]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	31	0.5	0.3	0.2	1.4	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	31	0.06	0.03	0.01	0.33	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	31	0.04	0.02	n.d.	0.27	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	31	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate (mg/l)	0.1	31	167	169	120	183	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	31	436	420	352	613	-----	-----	-----
Suspended Solids, Total (mg/l)	4	31	-----	n.d.	n.d.	13	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	31	3.0	2.9	2.1	4.0	-----	-----	-----
Iron, Total (ug/l)	40	12	233	218	80	440	-----	-----	-----
Iron, Dissolved (ug/l)	40	10	-----	n.d.	n.d.	70	-----	-----	-----
Manganese, Total (ug/l)	1	11	21.5	16.0	3.0	46.1	-----	-----	-----
Manganese, Dissolved (ug.l)	1	10	1.4	1.0	n.d.	4.0	-----	-----	-----
Silica, Total (ug/l)	20	18	3,142	3,167	2,346	3,899	-----	-----	-----
Silica, Dissolved (ug/l)	20	12	2,933	2,960	2,267	3,899	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	11	-----	1	n.d.	10	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	316	-----	n.d.	n.d.	10			
Microcystins (ug/l)	0.2	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 16.7; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.5. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near Indian Hills at monitoring station GARLK1428DW (L4) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	375	16.2	16.8	7.3	23.0	≤ 29.4(1) ≤ 18 3(1) ≤ 15.0(1)	0 96 250	0% 26% 67%
Dissolved Oxygen (mg/l)	0.1	375	7.6	7.9	3.2	10.7	≥ 5.0	27	7%
Dissolved Oxygen (% Sat.)	0.1	375	81.9	84.9	32.0	112.4	-----	-----	-----
Specific Conductance (umho/cm)	1	375	573	570	487	640	-----	-----	-----
pH (S.U.)	0.1	375	8.1	8.2	7.1	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	375	4.7	3.7	0.0	23.1	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	375	397	395	295	527	-----	-----	-----
Secchi Depth (in)	1	12	111	117	63	180	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	12	1821.7	1822.9	1813.8	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	8	157	154	145	176	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	8	0.15	0.13	0.09	0.24	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	5	0.59	0.39	0.39	1.30	3.8(2,3) 1.5(2,4)	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	5	0.8	0.7	0.5	1.4	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	8	0.02	0.02	0.01	0.06	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	8	0.02	0.02	0.01	0.04	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	8	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate (mg/l)	0.1	8	157	154	132	179	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	8	360	362	282	420	-----	-----	-----
Suspended Solids, Total (mg/l)	4	8	-----	n.d.	n.d.	5	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	8	3.1	3.0	2.9	3.5	-----	-----	-----
Iron, Total (ug/l)	40	1	190	190	190	190	-----	-----	-----
Iron, Dissolved (ug/l)	40	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/l)	1	1	28	28	28	28	-----	-----	-----
Manganese, Dissolved (ug.l)	1	1	2	2	2	2	-----	-----	-----
Silica, Total (ug/l)	20	7	3,348	3,312	3,079	3,653	-----	-----	-----
Silica, Dissolved (ug/l)	20	7	3,311	3,249	3,042	3,583	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	4	2.5	2.5	2	3	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	136	-----	n.d.	n.d.	9	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.2 and 16.8; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.6. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near Deepwater Bay at monitoring station GARLK1445DW (L5) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	445	16.8	17.1	8.1	23.9	≤ 29.4(1) ≤ 18 3(1) ≤ 15.0(1)	0 155 311	0% 35% 0.70
Dissolved Oxygen (mg/l)	0.1	445	7.2	7.7	1.1	9.6	≥ 5.0	46	10%
Dissolved Oxygen (% Sat.)	0.1	445	78.1	84.7	11.5	112.0	-----	-----	-----
Specific Conductance (umho/cm)	1	445	544	537	484	652	-----	-----	-----
pH (S.U.)	0.1	445	8.1	8.2	7.1	9.0	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	445	12	7.9	1.3	60.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	445	392	391	266	528	-----	-----	-----
Secchi Depth (in)	1	15	74	72	36	126	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	16	1819.6	1817.3	1812.6	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	27	153	151	140	172	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	27	0.12	0.11	n.d.	0.30	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	26	0.27	0.14	0.03	1.30	3.8(2,3) 1.5(2,4)	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	27	0.5	0.3	0.2	1.5	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	27	0.05	0.03	0.02	0.32	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	26	0.02	0.02	n.d.	0.08	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	27	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate (mg/l)	0.1	27	153	152	119	190	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	27	390	380	324	582	-----	-----	-----
Suspended Solids, Total (mg/l)	4	27	-----	5	n.d.	19	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	27	3.2	3.1	2.7	4.6	-----	-----	-----
Iron, Total (ug/l)	40	11	399	349	170	910	-----	-----	-----
Iron, Dissolved (ug/l)	40	9	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/l)	1	11	61.4	72.0	15.0	117.0	-----	-----	-----
Manganese, Dissolved (ug.l)	1	11	23.6	8.7	n.d.	82.0	-----	-----	-----
Silica, Total (ug/l)	20	17	3,557	3,641	2,026	5,358	-----	-----	-----
Silica, Dissolved (ug/l)	20	12	3,176	3,254	1,930	4,033	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	11	-----	2	n.d.	25	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	240	-----	1	n.d.	11	-----	-----	-----
Microcystins (ug/l)	0.2	3	-----	n.d.	n.d.	0.2	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.2 and 16.8; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.7. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near Independence Point at monitoring station GARLK1454DW (L6) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	280	17.3	17.1	8.3	23.8	≤ 29.4[1] ≤ 18 3[1] ≤ 15.0[1]	0 114 215	0% 41% 77%
Dissolved Oxygen (mg/l)	0.1	280	7.2	7.4	1.9	9.8	≥ 5.0	21	8%
Dissolved Oxygen (% Sat.)	0.1	280	78.5	81.9	20.6	120.6	-----	-----	-----
Specific Conductance (umho/cm)	1	280	507	492	422	631	-----	-----	-----
pH (S.U.)	0.1	280	8.0	8.1	7.0	8.6	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	280	14.3	11.2	3.7	91.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	280	394	388	325	487	-----	-----	-----
Secchi Depth (in)	1	12	50	52	19	84	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	12	1821.1	1822.9	1813.4	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	4	122	123	108	135	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	4	0.14	0.14	0.06	0.21	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	3	0.68	0.38	0.36	1.3	4.6[2,3] 1.7[2,4]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	3	1.0	0.7	0.7	1.5	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	4	0.07	0.06	0.03	0.13	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	3	0.04	0.05	0.02	0.05	-----	-----	-----
Sulfate (mg/l)	0.1	4	114	116	88	138	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	4	280	287	236	310	-----	-----	-----
Suspended Solids, Total (mg/l)	4	4	8.4	6	4.5	17	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	4	2.9	2.8	2.7	3.2	-----	-----	-----
Iron, Total (ug/l)	40	1	767	767	767	767	-----	-----	-----
Manganese, Total (ug/l)	1	1	61	61	61	61	-----	-----	-----
Manganese, Dissolved (ug.l)	1	1	12	12	12	12	-----	-----	-----
Silica, Total (ug/l)	20	3	4,143	4,113	3,627	4,689	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	3	4	5	3	5	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	109	-----	1	n.d.	10	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 17.1; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.8. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near New Town at monitoring station GARLK1481DW (L7) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	250	19.3	19.5	12.7	24.4	≤ 29.4(1) ≤ 18 3(1) ≤ 15.0(1)	0 150 244	0% 60% 98%
Dissolved Oxygen (mg/l)	0.1	250	7.6	7.8	4.6	9.4	≥ 5.0	2	1%
Dissolved Oxygen (% Sat.)	0.1	250	87.0	88.6	49.5	117.4	-----	-----	-----
Specific Conductance (umho/cm)	1	250	478	473	335	618	-----	-----	-----
pH (S.U.)	0.1	250	8.2	8.2	7.5	8.8	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	250	40.4	27.8	10.5	359.8	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	250	381	387	268	495	-----	-----	-----
Secchi Depth (in)	1	17	23	24	10	48	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	17	1819.4	1817.0	1812.6	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	23	128	127	79	178	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	23	-----	0.11	n.d.	0.44	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	23	0.29	0.23	n.d.	1.20	3.8(2,3) 1.2(2,4)	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	23	0.5	0.4	0.2	1.6	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	22	0.06	0.05	0.02	0.13	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	23	0.03	0.02	n.d.	0.07	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	23	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/l)	0.1	23	123	119	73	167	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	23	336	330	240	462	-----	-----	-----
Suspended Solids, Total (mg/l)	4	23	14.2	12	n.d.	60	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	23	2.9	2.8	2.5	4.3	-----	-----	-----
Iron, Total (ug/l)	40	10	1,297	979	210	3,556	-----	-----	-----
Iron, Dissolved (ug/l)	40	8	-----	n.d.	n.d.	70	-----	-----	-----
Manganese, Total (ug/l)	1	10	35	29	9	74	-----	-----	-----
Manganese, Dissolved (ug.l)	1	9	-----	2	n.d.	13	-----	-----	-----
Silica, Total (ug/l)	20	15	5,905	4,378	3,325	12,696	-----	-----	-----
Silica, Dissolved (ug/l)	20	11	3,912	4,086	3,043	4,224	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	11	4	2	n.d.	26	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	153	10	6	n.d.	100	-----	-----	-----
Microcystins (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.2 and 19.5; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.9. Summary of monthly (June through September) water quality conditions monitored in Lake Sakakawea near White Earth Bay at monitoring station GARLK1493DW (L8) during the period 2003 through 2005.

	Monitoring Results*						Water Quality Standards Attainment		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean****	**Median**	**Min.**	**Max.**	**State WQS Criteria*****	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Water Temperature (C)	0.1	71	20.9	22.2	15.6	25.3	≤ 29.4[(1)] ≤ 18 3[(1)] ≤ 15.0[(1)]	0 57 71	0% 80% 100%
Dissolved Oxygen (mg/l)	0.1	71	7.4	7.4	5.1	8.2	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	71	86.8	88.5	59.3	104.7	-----	-----	-----
Specific Conductance (umho/cm)	1	71	423	406	332	533	-----	-----	-----
pH (S.U.)	0.1	71	8.1	8.1	7.8	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	70	60.1	45.0	23.6	154.2	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	71	380	372	161	475	-----	-----	-----
Secchi Depth (in)	1	7	13	13	80	18	-----	-----	-----
Lake Surface Elevation (ft-msl)	0.1	7	1823.0	1825.0	1816.5	1827.0	-----	-----	-----
Alkalinity, Total (mg/l)	7	5	109	114	52	148	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	0.05	0.04	0.02	0.11	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	2	0.80	0.80	0.39	1.20	4.6[(2,3)] 1.2[(2,4)]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	3	0.7	0.7	0.1	1.4	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	5	0.06	0.06	0.04	0.09	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	5	-----	0.03	n.d.	0.07	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate (mg/l)	0.1	5	105	101	72	146	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	5	281	280	243	336	-----	-----	-----
Suspended Solids, Total (mg/l)	4	5	16.8	13	11	29	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	5	2.6	2.6	2.3	3.2	-----	-----	-----
Iron, Total (ug/l)	40	1	650	650	650	650	-----	-----	-----
Manganese, Total (ug/l)	1	1	17	17	17	17	-----	-----	-----
Silica, Total (ug/l)	20	4	4,251	4,223	4,073	4,486	-----	-----	-----
Silica, Dissolved (ug/l)	20	4	3,946	3,909	3,868	4,098	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab	1	3	4	4	3	5	-----	-----	-----
Chlorophyll *a* (ug/l) – Field	1	17	-----	27	n.d.	37	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 22.2; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.10. Summary of monthly (May through September) water quality conditions monitored in the Missouri River near Williston, North Dakota at monitoring Station GARNFMORRR1 (NF1) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	16	20.1	22.3	11.5	25.8	≤ 29.4(1) ≤ 18.3(1) ≤ 15.0(1)	0 11 12	0% 69% 75%
Dissolved Oxygen (mg/l)	0.1	16	8.0	7.7	7.0	9.5	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	16	91.6	91.9	79.0	101.4	-----	-----	-----
Specific Conductance (umho/cm)	1	16	527	563	374	631	-----	-----	-----
pH (S.U.)	0.1	16	8.3	8.3	7.9	8.7	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	16	277.9	117.4	37.6	>1,000	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	16	378	374	264	486	-----	-----	-----
Instantaneous Flow (cfs)	10	16	16,330	12,680	8,500	38,300	-----	-----	-----
Alkalinity, Total (mg/l)	7	16	147	157	89	188	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	18	-----	n.d.	n.d.	n.d.	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	15	0.24	0.16	0.01	0.72	3.1(2,3) 0.9(2,4)	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	16	0.62	0.57	0.26	1.3	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	18	0.24	0.16	0.04	0.81	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	18	0.04	0.02	n.d.	0.18	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	17	-----	n.d.	n.d.	0.01	-----	-----	-----
Sulfate (mg/l)	0.1	17	139	147	67	182	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	17	378	383	196	564	-----	-----	-----
Suspended Solids, Total (mg/l)	4	18	243	109	47	1,196	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	18	3.0	2.9	2.4	4.3	-----	-----	-----
Iron, Total (ug/l)	40	11	7,714	3,859	1,979	32,066	-----	-----	-----
Iron, Dissolved (ug/l)	40	11	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/l)	1	11	155	89	57	629	-----	-----	-----
Manganese, Dissolved (ug.l)	1	11	1.6	1.7	n.d.	4	-----	-----	-----
Silica, Total (ug/l)	20	15	11,591	10,178	3,756	37,547	-----	-----	-----
Silica, Dissolved (ug/l)	20	15	3,934	3,539	2,637	7,700	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean). The mean value for turbidity was calculated using a value of 1,000 for a measured value of >1,000.

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.3 and 22.3; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

Table 5.11. Summary of monthly (May through September) water quality conditions monitored in the Little Missouri River near Killdeer, North Dakota at monitoring station GARNFLMOR1 (NF2) during the period 2003 through 2005.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	6	22.2	21.4	20.5	26.3	≤ 29.4[(1)] ≤ 18.3[1)] ≤ 15.0[(1)]	0 6 6	0% 100% 100%
Dissolved Oxygen (mg/l)	0.1	6	7.3	7.0	6.4	9.4	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	6	87.7	85.0	77.0	110.4	-----	-----	-----
Specific Conductance (umho/cm)	1	6	1,590	1,590	1,250	1,854	-----	-----	-----
pH (S.U.)	0.1	6	8.3	8.2	8.1	8.7	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	6	>1,000	>1,000	63.6	>1,000	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	6	400	414	286	464	-----	-----	-----
Instantaneous Flow (cfs)	1	7	77	42	15	311	-----	-----	-----
Alkalinity, Total (mg/l)	7	8	297	286	200	468	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	8	-----	0.76	n.d.	1.6	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	6	0.27	0.29	0.02	0.45	3.8[(2,3)] 1.1[(2,4)]	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	8	4.4	5.2	0.6	8.0	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	8	3.16	3.65	0.06	5.60	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	5	0.07	0.06	0.02	0.16	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	5	-----	n.d.	n.d.	0.01	-----	-----	-----
Sulfate (mg/l)	0.1	8	521	567	159	881	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	8	1,570	1,420	990	2,435	-----	-----	-----
Suspended Solids, Total (mg/l)	4	8	5,564	6,705	41	10,700	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	8	11.2	11.0	9.5	13.0	-----	-----	-----
Iron, Total (ug/l)	40	3	73,505	1,846	1,660	217,010	-----	-----	-----
Iron, Dissolved (ug/l)	40	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/l)	1	3	1,066	146	144	2,908	-----	-----	-----
Manganese, Dissolved (ug.l)	1	2	36	36	26	45	-----	-----	-----
Silica, Total (ug/l)	20	7	29,557	16,278	4,438	82,985	-----	-----	-----
Silica, Dissolved (ug/l)	20	4	4,385	4,3015	4,262	4,676	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.2 and 21.4; respectively.

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

5.1.2.2 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal contour plots were prepared from the depth-profile water temperature measurements taken at sites L1, L2, L3, L4, L5, L6, L7, and L8 during the period 2003 through 2005 (Plates 1 through 12). As seen in Plates 1 through 12, temperatures in Lake Sakakawea vary longitudinally from the dam to the lake's upper reaches and vertically from the lake surface to the bottom. The near-surface water in the upper reaches of the lake warms up sooner in the spring than the near-surface water near the dam (Plates 1, 5, and 9). By mid-summer a strong thermocline becomes established in the lower reaches of the lake, and the near-surface waters of the entire lake above the thermocline are a fairly uniform temperature (Plates 2, 3, 6, 7, 10, and 11). As the near-surface waters of the lake cool in the late summer, the thermocline is pushed deeper and these wind-mixed upper waters are fairly uniform in temperature (Plates 4, 8, and 12). The vertical variation in temperature is most prevalent in the deeper area of the lake towards the dam where a strong thermocline becomes established during the summer. The shallower upper reaches of Lake Sakakawea do not exhibit much vertical variation of temperature during mid to late summer as wind action allows for complete mixing of the water column.

5.1.2.3 Summer Thermal Stratification

Lake Sakakawea exhibited significant thermal stratification during the summer of all 3 years (Plates 2, 3, 6, 7, 10, and 11). However, the lake was more weakly stratified in the summer of 2004 versus the summers of 2003 and 2005. Mid-summer epilimnetic water temperatures at station L1 near the dam were 3 to 5°C cooler in 2004 as compared to 2003 and 2005. The weaker stratification and cooler epilimentic temperatures in 2004 were attributed to the cooler, cloudy late-spring and early-summer climatic conditions that occurred in 2004. During maximum stratification in mid-summer, the thermocline in Lake Sakakawea in 2003, 2004, and 2005 was at a depth of about 25 meters (82 feet). The depth of the thermocline defines the upper limit of the hypolimnion. Where the corresponding elevation of the thermocline intersects the lake bottom defines the longitudinal boundary of the hypolimnion in Lake Sakakawea. During 2003 through 2005, the longitudinal boundary of the hypolimnion was in the Deepwater Bay/Independence Point area (i.e., River Mile 1450). Taking the slope of the lake bottom to be about 1.1 feet/mile along the old Missouri River channel, every foot of elevation increase in the pool elevation would extend the boundary of the hypolimnion about 0.9 mile up the lake.

5.1.2.4 Temporal Change in Bottom Water Temperatures in the Deeper Area of the Lake near the Dam

The near-bottom water temperatures measured at site L1 during 2003, 2004, and 2005 were plotted for comparison (Figure 5.1). The temperature of the near-bottom water appeared to be similar in 2004 and 2005, and about 2°C cooler in 2003. The near-bottom water temperature at site L1 exhibited a gradual warming from May through September in all 3 years, and the rate of warming appeared to be similar in all 3 years. A possible explanation for the colder near-bottom water temperatures in 2003 is the higher pool levels that occurred in Lake Sakakawea in 2003. Pool levels in 2004 and 2005 were similar and generally about 8 feet lower than those that were present in 2003. The deeper water conditions at site L1 in 2003 may have limited mixing and warming of the deeper water in the spring, and provided more volume of water in the hypolimnion to be warmed. Both situations may have resulted in the colder near-bottom water temperatures that occurred in 2003.

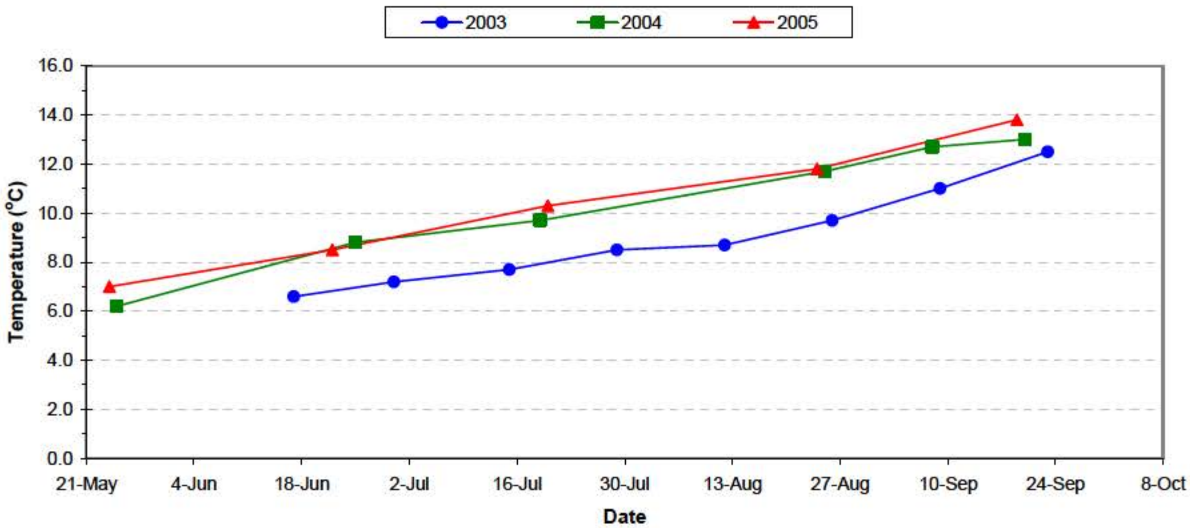


Figure 5.1. Near-bottom water temperatures measured at site L1 during the period 2003 through 2005.

5.1.3 DISSOLVED OXYGEN

5.1.3.1 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal contour plots were prepared from the depth-profile dissolved oxygen measurements taken at sites L1, L2, L3, L4, L5, L6, L7, and L8 during the period 2003 through 2005 (Plates 13 through 24). As seen in Plates 13 through 24, dissolved oxygen concentrations in Lake Sakakawea vary longitudinally from the dam to lake's upper reaches, and vertically from the lake surface to the bottom. Dissolved oxygen levels below 5 mg/l first appeared near the lake bottom in the upper middle reaches of the lake in July (Plates 14, 18, and 22). As the summer progressed, dissolved oxygen concentrations below 5 mg/l advanced along the lake bottom towards the dam (Plates 15, 19, and 23). By late summer, dissolved oxygen levels below 5 mg/l only occurred near the bottom in the deeper lacustrine area of the lake, as the near-bottom dissolved oxygen concentrations in the upper middle reaches of the lake had recovered to near saturation levels (Plates 16, 20, and 24). The earlier occurrence of low dissolved oxygen concentrations in the near-bottom water of the upper middle reaches is attributed to the increased organic loading in the transition zone of the reservoir and the lesser hypolimnetic volume available for assimilation of the oxygen demand. As this material decomposes, a "pool" of water with low dissolved oxygen levels accumulates near the bottom in this area of Lake Sakakawea. Decomposition of organic matter also occurs in the lacustrine zone and results in dissolved oxygen degradation as the summer progresses, although at a slower rate than what occurs in the transition zone. The recovery of near-bottom dissolved oxygen concentrations to saturation levels takes longer in the lacustrine zone because of the time needed for thermal stratification to breakdown and mixing within the water column to occur in the deeper water. The near-bottom location of the power tunnel intakes at the dam could also seemingly result in an interflow along the lake bottom that could promote the movement of oxygen demanding material and low dissolved oxygen water from the upper middle reaches of the lake to the dam. Any interflow affect would likely increase as pool levels and the reservoir's retention time decrease.

5.1.3.2 Temporal Change in Bottom Dissolved Oxygen Concentrations in the Deeper Area of the Lake near the Dam

The near-bottom dissolved oxygen concentrations measured at site L1 during 2003, 2004, and 2005 were plotted for comparison (Figure 5.2). The near-bottom dissolved oxygen concentrations at site L1 showed a steady rate of decline during all 3 years. The rate of decline appeared similar in 2004 and 2005, with a slower degradation rate occurring in 2003 (Figure 5.2). Near-bottom dissolved oxygen concentrations at site L1 fell below 5 mg/l by late summer in all 3 years (Figure 5.2). A possible explanation for the higher rate of dissolved oxygen degradation in 2004 and 2005 is that lower pool levels occurred in Lake Sakakawea in 2004 and 2005. Pool levels in 2004 and 2005 were similar and generally about 8 feet lower than those that were present in 2003. The lower pool levels in 2004 and 2005 resulted in less hypolimnetic volume and a shorter reservoir retention time than what occurred in 2003. The ability of Lake Sakakawea to assimilate oxygen demand is partly dependent upon the volume of the hypolimnion – the greater the hypolimnetic volume the greater its assimilative capacity. The shorter retention times in 2004 and 2005 may have allowed oxygen demanding materials and water with low dissolved oxygen concentrations to move to the area near the dam more rapidly than what may have occurred in 2003.

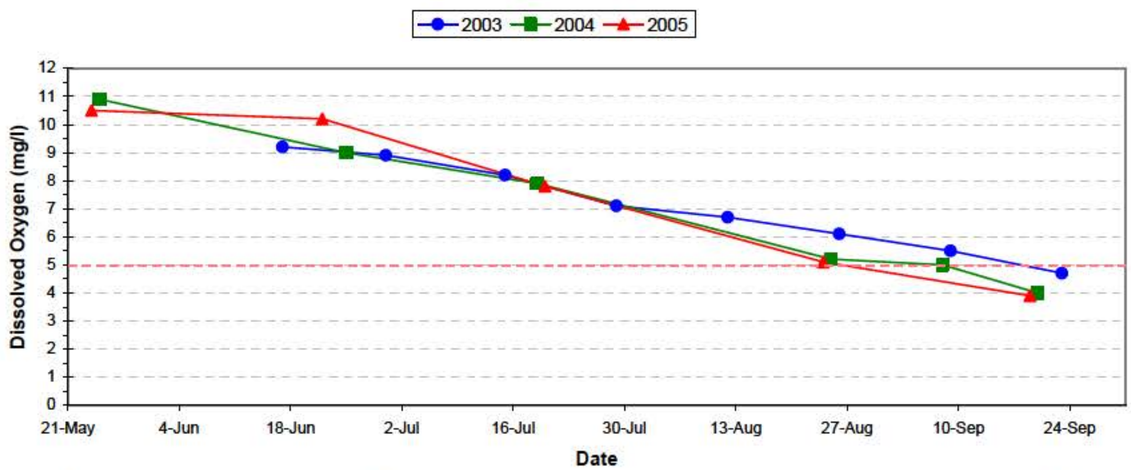


Figure 5.2. Near-bottom dissolved oxygen concentrations measured at site L1 during the period 2003 through 2005.

5.1.4 Water Clarity

5.1.4.1 Secchi Transparency

Figure 5.3 displays the distribution of the Secchi depth tranparencies measured at the eight in-lake monitoring sites as a box plot (note: the eight monitoring sites are oriented in an upstream to downstream direction along the x-axis). Secchi depth transparency increased significantly in a downstream direction from site L8 to site L4. Downstream of site L4, Secchi depth transparency did not show significant longitudinal variation. Under the conditions that were monitored during the 2003 to 2005 period, it appears that site L4 was in the vicinity of the boundary between the reservoir's transition zone and lacustrine zone.

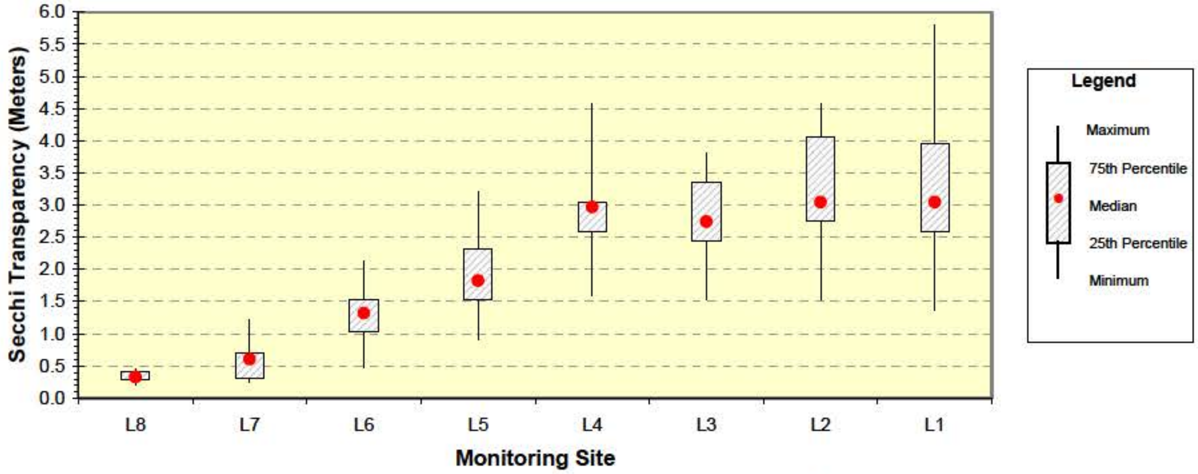


Figure 5.3. Box plot of Secchi transparencies measured at sites L1 through L8 during the period 2003 through 2005. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

5.1.4.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. Given the low chlorophyll *a* concentrations monitored, (Tables 5.1 through 5.9), turbidity in Lake Sakakawea is largely due to suspended inorganic material. Monthly (i.e., June, July, August, and September) longitudinal contour plots were prepared from the depth-profile turbidity measurements taken at sites L1, L2, L3, L4, L5, L6, L7, and L8 during the period 2003 through 2005 (Plates 25 through 35). As seen in Plates 25 through 35, turbidity levels in Lake Sakakawea vary longitudinally from the dam to lake's upper reaches, and vertically from the lake surface to the bottom. Turbidity levels are significantly higher in the upper reaches of the reservoir as compared to the area near the dam. This is attributed to the turbid conditions of the inflowing Missouri River. It also appears that turbidity plumes may move through Lake Sakakawea as interflows; especially along the bottom. This may be attributed to colder inflowing snowmelt runoff, with higher turbidity levels, flowing underneath warmer surface waters in Lake Sakakawea as an interflow along the bottom.

5.1.5 NUTRIENT CONDITIONS

5.1.5.1 Lake Trophic Status

Trophic State Index (TSI) values for Lake Sakakawea were calculated from the monitoring data collected at sites L1, L2, L3, L4, L5, L6, L7, and L8 during the period 2003 through 2005 (Table 5.12). The calculated TSI values indicate that the lacustrine zone of the lake (i.e., sites L1, L2, L3, and L4) is mesotrophic, the transition zone (i.e., sites L5 and L6) is moderately eutrophic, and the riverine zone (i.e., sites L7 and L8) is eutrophic. However, it is noted that the calculated average TSI value for the riverine zone is greatly influenced by the low water clarity in this part of the lake. This lack of water clarity is largely attributed to suspended inorganic material delivered to the lake by the Missouri River. Thus, the higher TSI values in the riverine zone may not be solely indicative of increased algal growth associated with nutrient enrichment.

Table 5.12. Mean Trophic State Index (TSI) values calculated for Lake Sakakawea at the eight in-lake monitoring locations based on measured Secchi depth, total phosphorus, and chlorophyll *a* values during the period 2003 through 2005.

Site	No. of Obs.	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phos.)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
L1	14	44	52	42	46
L2	4	41	56	43	47
L3	11	46	43	44	48
L4	4	46	46	48	47
L5	11	53	56	50	53
L6	3	61	57	54	57
L7	10	70	55	50	58
L8	3	76	60	53	63

5.1.5.2 Variation of Nutrient Levels with Lake Depth

Depth-discrete nutrient levels were determined based on near-surface, mid-depth, and near-bottom samples collected at site L1 during June through September over the period 2003 through 2005 (Table 5.13). Nutrient levels did not vary appreciably with depth.

Table 5.13. Mean and median depth discrete nutrient concentrations measured at site L1 during the period 2003 through 2005.

Nutrient	Near-Surface (0-5 Meters)	Mid-Depth (20-28 Meters)	Near-Bottom (35-42 Meters)
Kjeldahl N, Total (mg/l)			
• No. of Obs.	13	8	10
• Mean	0.6	0.4	0.4
• Median	0.3	0.3	0.3
Ammonia N, Total (mg/l)			
• No. of Obs.	13	8	10
• Mean	0.27	0.26	0.23
• Median	0.09	0.21	0.15
Nitrate-Nitrite N, Total (mg/)			
• No. of Obs.	13	8	10
• Mean	0.05	0.08	0.11
• Median	0.04	0.08	0.11
Phosphorus, Total (mg/l)			
• No. of Obs.	13	8	10
• Mean	0.07	0.04	0.04
• Median	0.04	0.02	0.03
Phosphorus, Dissolved (mg/l)			
• No. of Obs.	13	8	10
• Mean	0.02	0.03	0.03
• Median	0.02	0.03	0.03
Total Organic Carbon (mg/l)			
• No. of Obs.	11	8	6
• Mean	3.0	2.9	2.8
• Median	3.0	2.9	2.9

5.1.5.3 Missouri River Nutrient Flux Conditions

Nutrient flux rates for the Missouri River were calculated based on water quality samples collected near Williston, North Dakota (i.e. site NF1) and estimated instantaneous flow conditions at the time of sample collection (Table 5.14). The maximum nutrient flux rates are attributed to greater nonpoint source nutrient loadings associated with runoff conditions.

Table 5.14. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Williston, North Dakota during May through September over the period 2003 through 2005.

Statistic	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	15	15	16	16	16	16
Mean	0.093	0.315	-----	0.145	0.017	1.456
Median	0.085	0.207	n.d.	0.049	0.010	1.036
Minimum	0.003	0.111	n.d.	0.010	n.d.	0.626
Maximum	0.324	1.382	0.298	0.861	0.068	4.572

n.d. = non-detectable.
Note: Statistics of Missouri River flows used for flux calculations were: mean = 16,327 cfs, median = 12,680 cfs, minimum = 8,500 cfs, and maximum = 38,300 cfs.

5.1.6 PHYTOPLANKTON COMMUNITY

Forty-five individual phytoplankton grab samples were collected from Lake Sakakawea at sites L1, L3, L5, and L7 during the period 2003 through 2005. Collected algae included taxa from the following seven taxonomic Divisions: Bacillariophyta (Diatioms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). Plate 36 summarizes the percent taxa composition by Division, based on biovolume, of the monthly phytoplankton samples. The prevalence of these groups of algae in Lake Sakakawea from greatest to least, based on taxa occurrence and abundance, were Bacillariophyta > Chlorophyta/Cryptophyta > Cyanobacteria > Pyrrophyta > Chrysophyta >> Euglenophyta. The diatoms were generally the most prevalent algae throughout the entire sampling period. Plate 37 lists the algal genera/species collected and their frequency of occurrence and relative abundance. No significant concentrations of the microcystins toxin were monitored in Lake Sakakawea.

5.2 COLDWATER HABITAT IN LAKE SAKAKAWEA

5.2.1 ANNUAL OCCURRENCE OF COLDWATER HABITAT

The occurrence of coldwater habitat in Lake Sakakawea is directly dependent on the lake's annual thermal regime. Early in the winter ice-cover period, the entire lake volume will be supportive of coldwater habitat. As the winter ice-cover period continues, lower dissolved oxygen concentrations will likely occur near the bottom as organic matter decomposes and lake mixing is prevented by ice cover. As dissolved oxygen concentrations in the near-bottom water fall below 5 mg/l, coldwater habitat will not be supported. During the spring isothermal period water temperatures and dissolved oxygen levels in the entire lake volume will be supportive of coldwater habitat. During the early-summer lake warming period, coldwater habitat will progressively decrease as water temperatures in the epilimnion become non-supportive of coldwater habitat. During mid-summer when Lake Sakakawea is experiencing maximum thermal stratification, water temperatures will only be supportive of coldwater habitat in the hypolimnion. Theoretically, coldwater habitat should remain stable during this period unless degradation of dissolved oxygen concentrations near the lake bottom become non-supportive of coldwater habitat. The most crucial period for the support of coldwater habitat in Lake Sakakawea is when the lake begins to cool in late summer. As the thermocline moves deeper, the volume of the coldwater hypolimnion will continue to decrease while the expanding epilminion may not yet be cold enough to be supportive of coldwater habitat. At the same time, hypolimnetic dissolved oxygen concentrations are approaching their maximum degradation and low dissolved oxygen levels are moving upward from the lake bottom and pinching off coldwater habitat from below. This situation will continue to worsen until the epilimnion cools enough to be supportive of coldwater habitat. When fall turnover occurs, dissolved oxygen concentrations at all depths will be near saturation and supportive of coldwater habitat. However, depending on the hydrologic conditions of the lake, the isothermal lake temperature at the beginning of fall turnover may not be supportive of all coldwater habitats. This situation will continue to occur until the isothermal lake temperature cools to 15°C, at which time the entire lake volume will be supportive of all coldwater habitat types. As the lake continues to cool, temperatures will remain isothermal until the lake cools to 4°C, and the entire lake will be supportive of coldwater habitat.

The rate of decline of coldwater habitat in Lake Sakakawea is seemingly exacerbated by the bottom withdrawal and discharge of hypolimnetic water through Garrison Dam during the summer. The withdrawal and discharge of hypolimnetic water through the dam could impact the coldwater habitat in Lake Sakakawea in the following three ways: 1) reduce and the volume of the hypolimnion, 2) cause warming of the hypolimnion, and 3) enhance the movement of water with higher oxygen demands and low dissolved oxygen concentrations along the lake bottom from the lake's upper reaches to the dam. When thermal stratification becomes established in late spring, the quiescent hypolimnion becomes isolated from the rest of the lake and will not be replenished unless there is a coldwater inflow (e.g., tributaries, ground water "springs", etc.). As the bottom withdrawal evacuates hypolimnetic water, it will be replaced by water from within the lake. This will induce mixing within the hypolimnion and destabilize the thermocline due to heat transfer from the metalimnion as the evacuated water is replaced. The bottom withdrawal may also result in an interflow along the bottom of the lake that draws water from the upper reaches of the lake to the dam. An interflow along the lake bottom could enhance the movement of oxygen demanding materials and water with low dissolved oxygen concentrations along the lake bottom from the upper reaches of the lake to the dam.

5.2.2 INTERACTION OF WATER TEMPERATURE AND DISSOLVED OXYGEN IN DETERMINING THE OCCURRENCE OF COLDWATER HABITAT

The occurrence of coldwater habitat is determined by the interaction of water temperature and dissolved oxygen concentrations as they vary with lake depth. The interaction of varying water temperature and dissolved oxygen with depth in determining the occurrence of optimal coldwater habitat at the near-dam, deepwater station (i.e., site L1) is shown in Figure 5.4. Figure 5.4 plots the 15°C water temperature and 5 mg/l dissolved oxygen concentration isopleths at station L1 for 2003, 2004, and 2005. Optimal coldwater habitat is represented by the area between the 15°C and 5 mg/l isopleths. As shown in Figure 5.4, the increasing depth of 15°C water and the decreasing depth to 5 mg/l dissolved oxygen concentrations during the summer, resulted in a steady decline in the occurrence of optimal coldwater habitat at site L1.

5.2.3 OCCURRENCE OF COLDWATER HABITAT DURING THE PERIOD 2003 THROUGH 2005

The volumes of optimal, marginal, and total coldwater habitat estimated to be present in Lake Sakakawea during 2003 to 2005 are given in Plates 38 through 54. Figures 5.5, 5.6, and 5.7 respectively show the amount of optimal, marginal, and total coldwater habitat estimated to have been present in Lake Sakakawea during 2003, 2004, and 2005. Figure 5.8 compares the amount of optimal coldwater habitat estimated to be present in Lake Sakakawea during 2003, 2004, and 2005. The estimated optimal coldwater habitat progressively decreased from June through September in all 3 years (Figures 5.5 through 5.8). The marginal coldwater habitat estimated to be present in Lake Sakakawea increased then decreased then dramatically increased in all 3 years (Figures 5.5 through 5.7). The estimated total coldwater habitat progressively decreased then dramatically increased in all 3 years (Figures 5.5 through 5.8). The estimated occurrence of coldwater habitat in Lake Sakakawea during 2003 through 2005 was generally in line with the expected annual thermal cycle. The rate of decline of optimal coldwater habitat during late-summer may have been less in 2005 as compared to 2003 and 2004 (Figure 5.8). This may have been a result of implementing the short-term water quality management measures at Garrison Dam in the mid-summer of 2005.

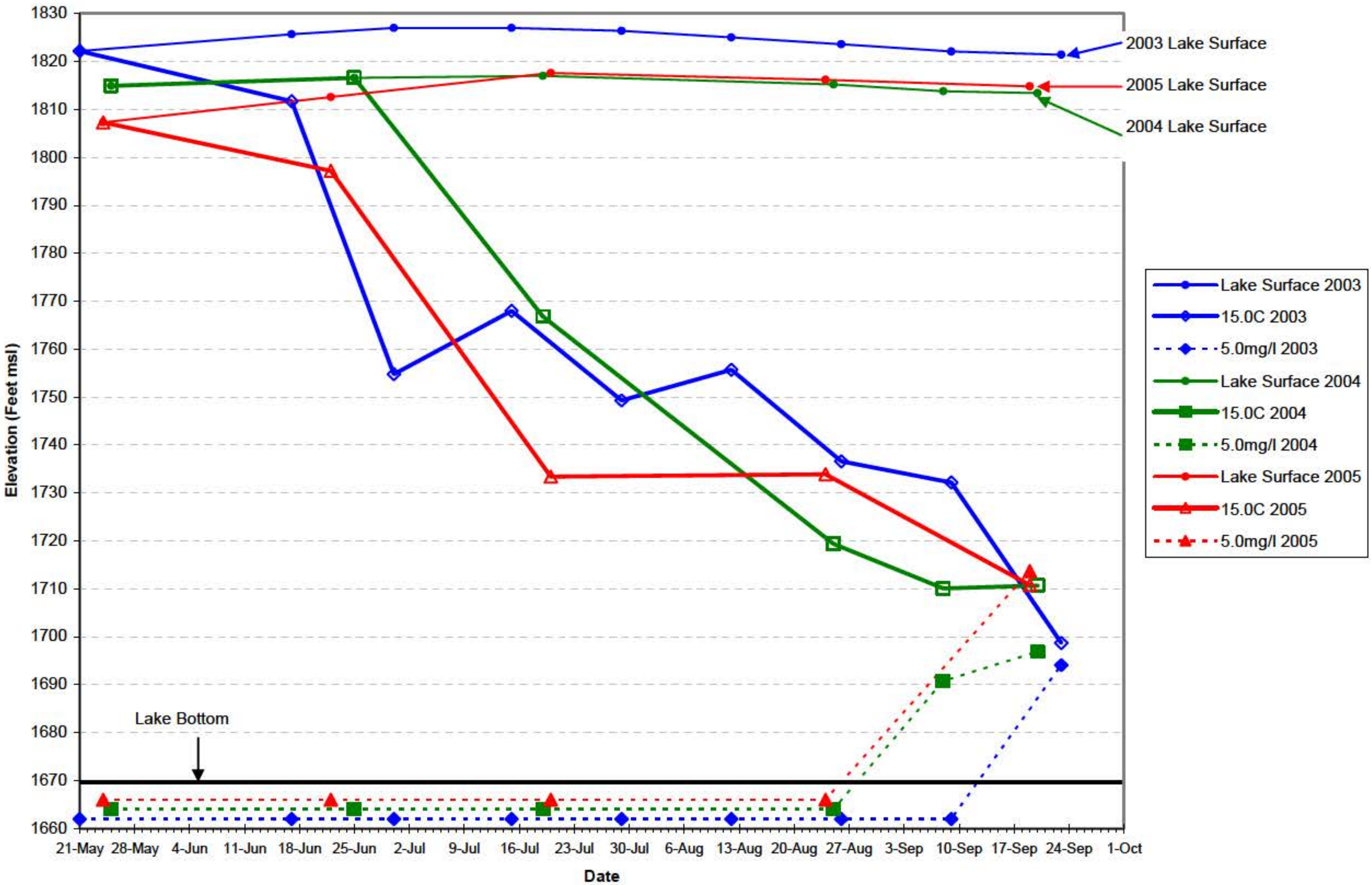


Figure 5.4. Elevation of lake surface and 15°C water temperature and 5 mg/l dissolved oxygen concentration isopleths by year for station L1.

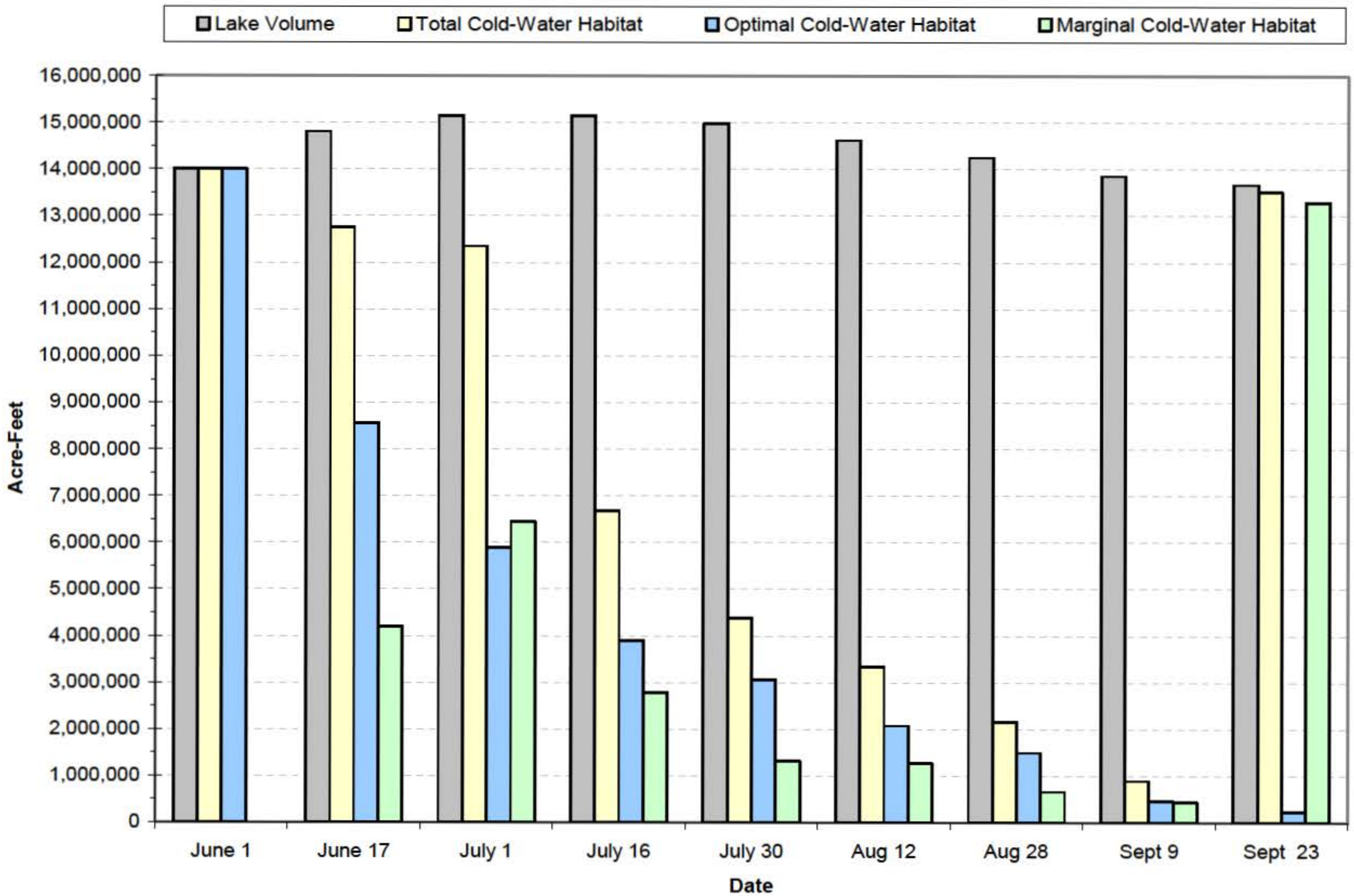


Figure 5.5. Estimated volume of coldwater habitat in Lake Sakakawea during 2003.

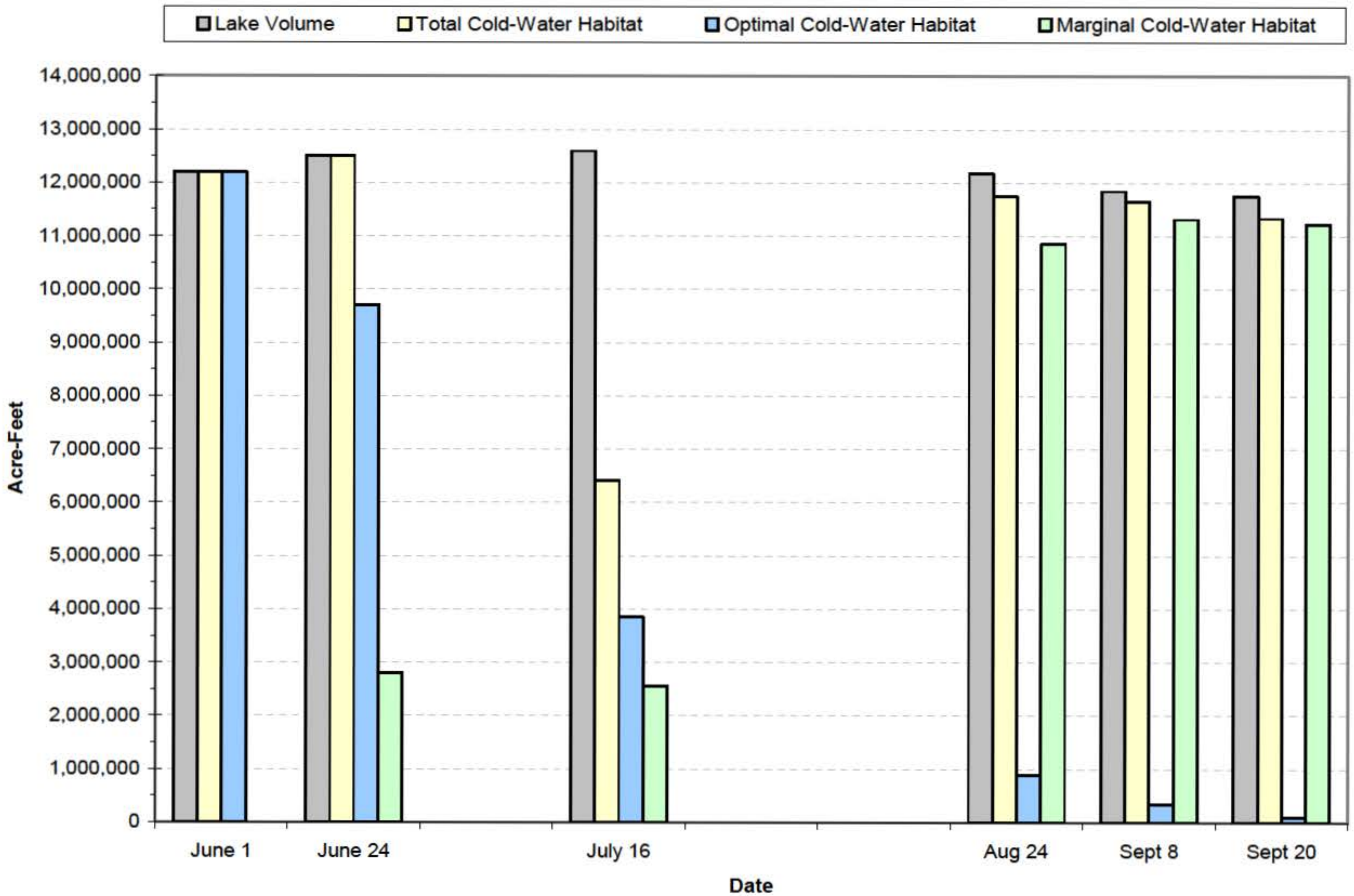


Figure 5.6. Estimated volume of coldwater habitat in Lake Sakakawea during 2004.

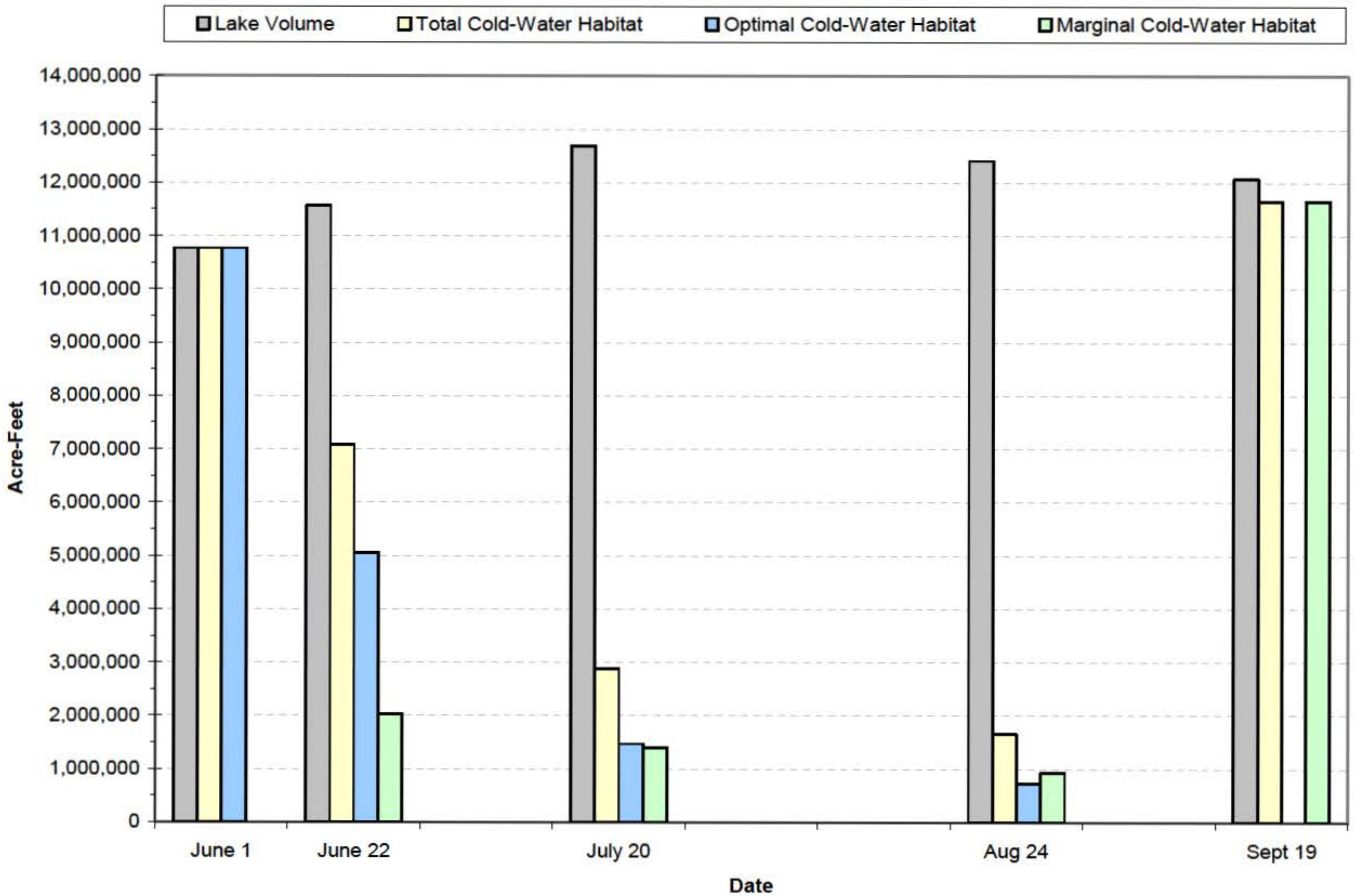


Figure 5.7. Estimated volume of coldwater habitat in Lake Sakakawea during 2005.

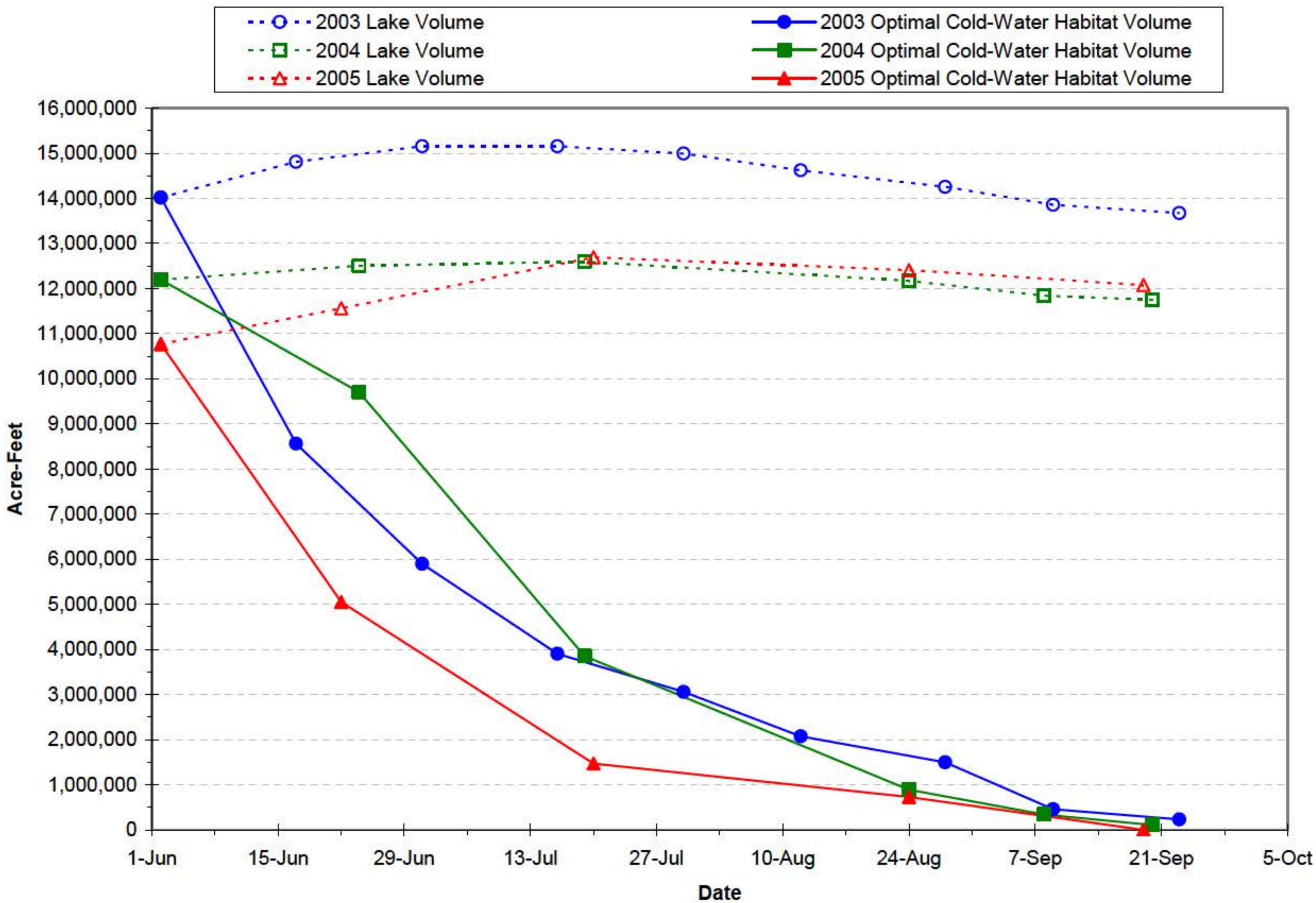


Figure 5.8. Estimated volume of optimal coldwater habitat in Lake Sakakawea during 2003, 2004, and 2005.

6 WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH GARRISON DAM AND IN THE SUBMERGED INTAKE CHANNEL TO GARRISON DAM

6.1 WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH GARRISON DAM

6.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Table 6.1 summarizes the water quality conditions that were monitored monthly in the Garrison Dam powerhouse during the period 2003 through 2005. These results indicate no major water quality concerns other than the possible situation regarding water temperature and dissolved oxygen for the support of coldwater habitat.

6.1.2 WATER TEMPERATURE

Continuous monitoring of water quality conditions of water drawn from the "raw water loop" within Garrison Dam was started on June 17, 2003. Plots of the hourly water temperatures recorded at this site from June 17, 2003 through July 15, 2005 are shown in Plates 55 through 62. Also shown on these plots is the hourly discharge rate of Garrison Dam. The monitoring of water quality conditions in the raw water loop was discontinued on July 16, 2005. Continuous monitoring of water quality conditions of water drawn from each of the five individual penstocks was started on July 21, 2005. Plots of the flow-weighted hourly average water temperature and dam discharge rate for the period July 21 through September 30, 2005 are shown in Plate 63. Hourly water temperatures and discharge rates monitored in each of the five individual penstocks for the period July 21 through September 30, 2005 are plotted in Plates 64 through 68. During the January through March period water temperatures were fairly stable below 4°C and exhibited only minor fluctuation with changing dam discharge rates (Plates 57 and 61). From April through June, water temperatures exhibited a steady increase to a maximum of about 15°C at the end of the period, and significant fluctuation of temperature with dam discharge started around June 1 (Plates 58 and 62). During the July through September period water temperatures continued to increase, albeit gradually, and significant fluctuations with flow continued (Plates 55, 59, and 63). From September through December, water temperatures exhibited a steady decline to below 4°C and little fluctuation with changing dam discharge rates.

6.1.3 DISSOLVED OXYGEN

Plots of the hourly dissolved oxygen concentrations recorded on water drawn from the "raw water loop" from June 17, 2003 through July 15, 2005 are shown in Plates 69 through 76. Also shown on these plots is the hourly discharge rate of Garrison Dam. Hourly dissolved oxygen concentrations and discharge rates monitored in each of the five individual penstocks for the period July 21 through September 30, 2005 are plotted in Plates 77 through 81. During the January through March period dissolved oxygen levels varied considerably with dam discharge, but remained near or above 8 mg/l (Plates 71 and 75). From April through June, dissolved oxygen levels exhibited a steady decrease to a minimum of about 7 mg/l at the end of the period, and little fluctuation of dissolved oxygen with dam discharge was noted (Plates 72 and 76). During the July through September period dissolved oxygen levels continued to decrease and considerably fluctuations with dam discharge occurred (Plates 69, and 73). From September through December, dissolved oxygen levels exhibited a steady increase to about 12 mg/l and little fluctuation with changing dam discharge rates.

Table 6.1. Summary of monthly (year-round) water quality conditions monitored in the Garrison Dam discharge water at monitoring station GARPP1 (OF1) during the period 2003 through 2005.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria**	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (C)	0.1	24	10.3	11.0	1.3	18.0	≤ 29.4(1) ≤ 18.31) ≤ 15.0(1)	0 0 5	0% 0% 21%
Dissolved Oxygen (mg/l)	0.1	24	8.4	8.0	4.4	12.3	≥ 5.0	1	4%
Dissolved Oxygen (% Sat.)	0.1	24	78.8	85.2	44.6	98.2	-----	-----	-----
Specific Conductance (umho/cm)	1	22	575	563	481	659	-----	-----	-----
pH (S.U.)	0.1	24	8.1	8.1	7.4	8.9	≥6.5 & ≤9.0	0	0%
Dam Discharge (cfs)	10	24	18,720	18,950	9,450	29,000	-----	-----	-----
Alkalinity, Total (mg/l)	7	22	169	170	158	182	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	22	0.09	0.08	n.d.	0.18	-----	-----	-----
Ammonia, Total (mg/l)	0.01	21	0.21	0.12	n.d.	0.66	4.6(2,3) 2.6(2,4)	0 0	0% 0%
Kjeldahl N, Total (mg/l)	0.1	21	0.9	0.4	0.2	8.8	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	22	-----	0.03	n.d.	0.30	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	15	-----	0.02	n.d.	0.14	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	22	-----	n.d.	n.d.	0.25	-----	-----	-----
Sulfate (mg/l)	0.1	22	166	169	128	188	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	22	405	402	236	530	-----	-----	-----
Suspended Solids, Total (mg/l)	4	22	-----	n.d.	n.d.	21	-----	-----	-----
Organic Carbon, Total (mg/l)	0.05	21	2.9	2.9	2.5	3.3	-----	-----	-----
Iron, Total (ug/l)	40	19	222	151	n.d.	961	-----	-----	-----
Iron, Dissolved (ug/l)	40	17	-----	n.d.	n.d.	112	-----	-----	-----
Manganese, Total (ug/l)	1	19	14.9	10	3	64	-----	-----	-----
Manganese, Dissolved (ug.l)	1	17	-----	1	n.d.	7.8	-----	-----	-----
Silica, Total (ug/l)	20	6	4,238	3,304	2,976	6,600	-----	-----	-----
Silica, Dissolved (ug/l)	20	6	3,652	3,041	2,916	6,600	-----	-----	-----
Pesticide Scan (ug/l)***	0.05	2	-----	n.d.	n.d.	n.d.	****	0	0%

n.d. = Not detected.

* Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The arithmetic mean was not calculated for pH because pH values are logarithmic.

** (1) Numeric temperature criterion given in North Dakota water quality standards is 29.4 C. No specific numeric temperature criteria are identified for coldwater aquatic life. The 18.3 and 15 C levels are given for comparison purposes.

(2) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values of 8.1 and 10.3; respectively .

(3) Acute criterion for aquatic life.

(4) Chronic criterion for aquatic life.

*** The pesticide scan includes: acetochlor, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

**** Some pesticides do not have water quality standards criteria defined, and for those pesticides that have criteria, the criteria vary.

6.2 WATER QUALITY CONDITIONS IN THE SUBMERGED INTAKE CHANNEL TO GARRISON DAM

6.2.1 NEAR-DAM WITHDRAWAL ZONE WITHIN LAKE SAKAKAWEA

Garrison Dam is approximately 2 miles long and runs along a northwest-southeast axis. The old Missouri River channel is near the east end of the dam and the outlet works are near the west end of the dam. During construction of the dam, a channel (i.e., intake channel) was excavated to carry Missouri River flows around the dam construction area. The intake channel joins the old Missouri River channel approximately 1 mile out from the dam then quarters to the dam until making a sharp turn to perpendicularly meet the dam at the intake structure (Figure 3.2). The intake channel was constructed as follows: 1) it has a constant bottom elevation of 1670 ft-msl, 2) it is about 2-1/2 miles long and 500 feet wide, and 3) it has an excavated depth of about 100 feet near the dam intake structure. The intake channel was covered with water when the dam was closed and is now submerged by Lake Sakakawea. The portals to the power tunnels at the intake structure extend from elevations 1672 to 1698 ft-msl. The invert elevation of 1672 ft-msl for the power tunnel portal is 2 feet above the lake bottom. Water flowing into the power tunnels must move through the intake channel. Thus, water on the bottom of the lake is drawn into the dam along the bottom of the intake channel, whereas water higher up in the water column must travel down the "sides" of the intake channel. Due to the design of the intake structure and intake channel, the vertical extent of the withdrawal zone in Lake Sakakawea is dependent on the discharge rate of the dam. As dam discharge rates increase, water is pulled down from higher elevations within the lake.

The varying vertical extent of the in-lake withdrawal zone with dam discharge rate is quite evident during summer thermal stratification. When the lake is thermally stratified in the summer high discharge rates result in warmer water temperatures with higher dissolved oxygen concentrations being drawn into the dam from higher elevations within the lake (Plates 55, 59, 69, and 73). Under low dam discharge conditions, water is drawn into the dam from lower lake elevations and reflective of water quality conditions near the lake bottom – colder and lower in dissolved oxygen (Plates 55, 59, 69, and 73). The water quality management measures implemented during the summer of 2005 (i.e., plywood barriers, lowering head gates, and flow modification) attempted to manage this situation by allowing water to be drawn into the dam from higher elevations in Lake Sakakawea under high and low discharge periods.

6.2.2 WATER TEMPERATURE AND DISSOLVED OXYGEN CONDITIONS

Water temperature and dissolved oxygen depth profiles were collected at six locations along the submerged intake channel during July through September 2005 (Figure 3.2). Plate 82 shows temperature depth profiles that were measured along the submerged intake channel on July 26, August 24, and September 19, 2005. The bottom withdrawal and configuration of the intake channel clearly affected thermal stratification near the dam based on the temperature depth profiles measured in July, August, and September. As seen in Plate 82, the thermocline at sites GARLK1390B1 (B1) and GARLK1390B2 (B2) was drawn down compared to the thermocline depth at the sites farther away from the dam. Dissolved oxygen depth profiles showed little variation along the submerged intake channel for the three dates sampled.

7 EVALUATION OF IMPLEMENTED SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

(Note: A separate report, "Garrison Cold Water Fishery Alternatives Performance Assessment" (USACE, June 2006), was prepared that assesses the performance of the implemented short-term water quality management measures.)

7.1 IMPLEMENTATION OF SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

7.1.1 MODIFICATION OF THE DAM'S INTAKE TRASH RACKS

The power tunnels at Garrison Dam are screened at the upstream end of the water passage by trash racks. These trash racks prevent large objects from entering the penstocks and causing serious damage to the wicket gates and turbine. Each of the five penstocks has two intake passages for a total of ten intakes. The trash rack for each of the ten intakes consists of seven separate frame sections. The trash rack fits into the trash rack slots at the front of the intake passage piers. A hook for each rack is fixed to the top of the frame. A lifting beam and mobile crane is used to raise and lower each trash rack.

The existing trash racks were modified to raise the elevation where water was withdrawn from Lake Sakakawea. The trash rack modification consisted of installing plywood sheathing on the upstream side of the existing trash rack grates on the passages to penstocks 2 and 3. The plywood sheathing covered the lower 48 feet of the trash racks (i.e., approximately elevation 1672 to 1720 ft-msl) with the exception of a 3-inch slot at the very bottom for passing sediments. The plywood installation was completed on the trash racks to penstock 3 on July 15, 2005 and on the trash racks to penstock 2 on July 20, 2005. Unfortunately, Unit 3 experienced an unscheduled outage on July 30, 2005. Unit 3 was brought back on-line on September 20, 2005. The positive impact of the plywood barrier installation was likely reduced during the period of Unit 3 non-operation, as water was not drawn through the penstock.

7.1.2 UTILIZATION OF HEAD GATES TO RESTRICT THE OPENING TO THE DAM'S POWER TUNNELS

Each of the intake passages to all five power tunnels have operational head gates that can control flow into the tunnels. It was reasoned that lowering one of the two head gates to block a single passage to the power tunnel should increase the velocity of water drawn into the power tunnel, given the total flow through the power tunnel remained the same. Increasing the velocity of the water drawn into the intake could pull water from a higher elevation within Lake Sakakawea and possibly help maintain the lake's deeper, colder volume. To implement this measure, the head gate on one of the passages to penstock 1 was lowered on August 18, 2005 and on one of the passages to penstock 4 on September 1, 2005.

7.1.3 MODIFICATION OF DAILY FLOW CYCLE AND MAXIMUM AND MINIMUM FLOW RELEASES

Past water quality monitoring at the Garrison Dam powerhouse indicated that the vertical extent of the withdrawal zone in Lake Sakakawea, during summer thermal lake stratification, was dependent on the discharge rate of the dam. Warmer water high in dissolved oxygen was drawn down from higher elevations in the lake under higher discharge rates, and colder water low in dissolved oxygen was drawn from the lower depths of the lake under lower discharge rates. The influence of the dam's discharge rate on the lake withdrawal zone is believed to be partly attributed to the design of the intake structure and submerged intake channel.

To the extent possible, flow releases from Garrison Dam were modified to try to maximize the water drawn from higher elevations and minimize the water drawn from lower elevations in Lake Sakakawea. The following two flow release modifications were pursued: 1) daily flow releases should be in either a maximum or minimum mode, and 2) minimum flows should be discharged through penstocks 2 and 3 which have the plywood sheathing in place.

7.2 EFFECT OF IMPLEMENTED MEASURES ON WATER QUALITY MONITORED IN THE GARRSION POWERHOUSE PENSTOCKS

As previously discussed, continuous monitoring of water quality conditions of water drawn from each of the five individual penstocks was started on July 21, 2005. This monitoring continuously logged water quality conditions in the penstocks 24 hours a day irregardless of whether flow was occurring in the penstock (i.e., the turbine located on the penstock was generating power). The term dynamic is used to delineate water quality measurements taken during periods when flow was occurring in the penstocks. Plate 83 shows a combined plot of water temperatures measured in penstocks 1, 2, 3, 4, and 5 during the period July 21 through September 30, 2005. Plate 84 provides a plot of dynamic water temperatures measured in the five penstocks over the same time period.

7.2.1 TRASH RACK MODIFICATION

Water quality conditions monitored in the five penstocks during the period July 21 through September 30 were used to evaluate the affects of the plywood trash rack barriers on penstocks 2 and 3. As noted earlier, penstock 3 experienced an unscheduled outage on July 30 through September 20 and limited data are available to evaluate the affects of the plywood trash barrier on penstock 3. Penstock 2, however, remained operational throughout the period of evaluation. Plate 84 clearly indicates that dynamic water temperatures measured in penstocks 2 were warmer than the dynamic flows measured in penstocks 1, 4, and 5 with the unaltered trash racks. Dynamic water temperatures monitored in penstock 2 were generally between 15 and 19°C (Plate 84). This was about 4°C warmer than water temperatures monitored in penstocks 1, 4, and 5. The warming of the water in penstocks 1, 4, and 5 to above 15°C in the first part of September was attributed to the capture of warmer water as the epilimnion expanded downward in Lake Sakakawea as the lake approached fall overturn. The penstock monitoring data indicate that the plywood trash rack barriers met their design objective. The plywood barriers allowed warmer water from a higher elevation in Lake Sakakawea to be drawn into the penstocks that were treated.

7.2.2 LOWERING PENSTOCK HEAD GATES

Water quality conditions monitored in penstocks 1, 4, and 5 were used to evaluate the affects of lowering one head gate in penstocks 1 and 4. Plate 85 shows a plot of dynamic temperatures measured in penstocks 1, 4, and 5 during the period August 14 through September 18, 2005 and identifies when the head gates on one of the two portals to penstocks 1 and 4 were lowered. Dynamic water temperatures monitored in penstocks 1, 4, and 5 were similar prior to August 18 (Plate 85). Dynamic water temperatures in penstock 1 show about a 2°C warming after the one head gate was lowered on August 18 (Plate 85). A similar situation also occurred in penstock 4 when one head gate was lowered on September 1 (Plate 85). The affects of the head gate lowering on penstock 4 is not as clear due to the warming of dynamic water temperatures in penstock 5 due to the downward expansion of the epilimnion in Lake Sakakawea. It does appear that restricting the opening to the penstocks by lowering one head gate does allow for water to be drawn into the penstock from a higher elevation in Lake Sakakawea. The resulting increased velocity of the water drawn into the treated penstocks did not seem to have any deleterious effect.

7.2.3 MODIFICATION OF DAM RELEASES

Operating Garrison Dam to allow for daily releases to be in either a maximum or minimum mode was implemented to the degree possible given the power demands placed on the facility. Discharging minimum flows through either penstocks 2 or 3 was not accomplished due to the unscheduled outage of penstock 3. Penstock 2 was used to the maximum extent possible to discharge minimum daily flows.

The utilization of the five penstocks to discharge water during the period July 21, through September 30, 2005 was determined from operational records of the Garrison powerhouse. For assessment purposes, minimum daily flow was defined as two or less penstocks in operation and maximum daily flow was defined as three or more penstocks in operation. The July 21 through September 30 period was also subdivided into the two times periods of July 21 to September 5 and September 6 to September 30. As was noted above, dynamic water temperatures below 15°C did not occur in any of the unmodified penstocks after early September. Figure 7.1 shows the total water discharged through Garrison Dam via the various penstocks under minimum and maximum daily flows.

During July 21 through September 30, daily periods of maximum and minimum discharges from Garrison Dam generally occurred for about 6 and 18 hours respectively. This daily discharge pattern approached the desired goal of operating Garrison Dam in either a maximum or minimum discharge mode. This resulted in about equal volumes of water being discharged daily under minimum and maximum flows (Figure 7.1). During the period July 21 to September 5 33 percent of the volume discharged under minimum flows passed through penstocks 2 and 3 (Figure 7.1). This fell short of the desired goal of maximizing the discharge of minimum flows through the two penstocks with the modified trash racks. As was noted, penstock 3 experienced an unscheduled outage for most of this period. During the entire July 21 to September 30 period, 2,127,136 acre-feet of water was discharged from Garrison Dam with 39 percent of this volume passing through penstocks 2 and 3.

7.3 POTENTIAL PRESERVATION OF COLDWATER HABITAT IN LAKE SAKAKAWEA DUE TO THE IMPLEMENTATION OF SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

The potential impact of implementing the short-term water quality management measures on preserving the coldwater habitat in Lake Sakakawea during the period July 22, through September 30, 2005 was estimated by comparing the quantity of water meeting optimal coldwater conditions (i.e., ≤ 15°C and ≥ 5 mg/l dissolved oxygen) that was discharged through each of the penstocks. For comparison purposes, the water quality conditions monitored in penstocks 2 and 3 were compared to penstocks 4 and 5. The water quality conditions monitored in penstocks 4 and 5 were taken to be the water quality conditions that would have occurred in penstocks 2 and 3 if the plywood barriers were not in place. As is shown in Plate 84, most of the water discharged through penstocks 4, and 5 prior to September 1 met the defined optimal coldwater habitat conditions, while almost all the water discharged through penstocks 2 and 3 did not (i.e., water was warmer than 15°C). This resulted in a potential saving of about 379,390 acre-feet of optimal coldwater habitat in Lake Sakakawea over the 60-day period (Figure 7.2). All of the potential savings of optimal coldwater habitat occurred prior to September 4 (Figure 7.2). No water meeting optimal coldwater habitat criteria was discharge through Garrison Dam after September 4 based on monitoring of dynamic water quality conditions in the five penstocks. After September 4, dynamic water temperatures in all the penstocks were above 15°C due to the downward expansion of the epilimnion in Lake Sakakawea.

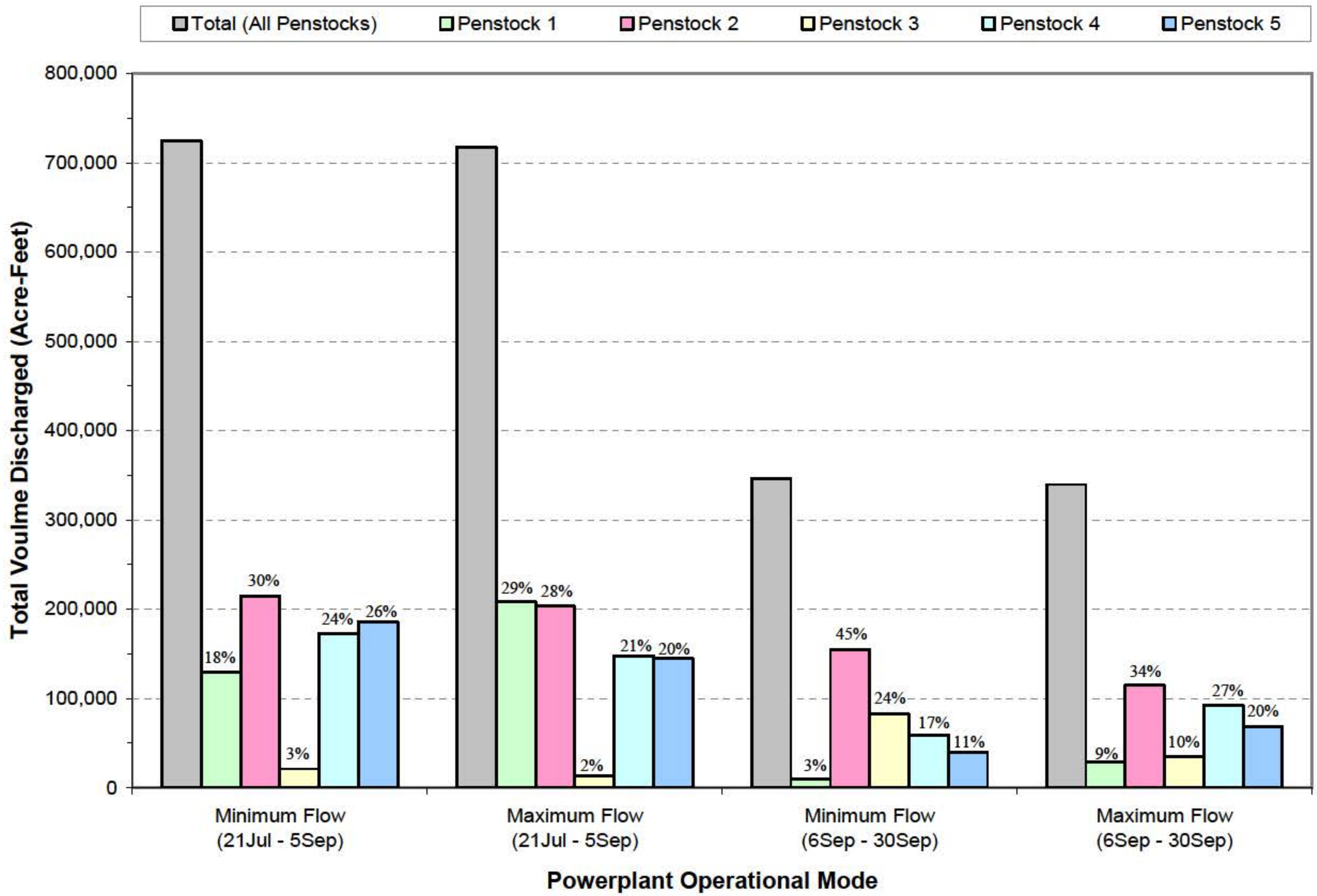


Figure 7.1. Total water discharged through Garrison Dam via the various penstocks under minimum and maximum daily flows during the period July 21 through September 30, 2005.

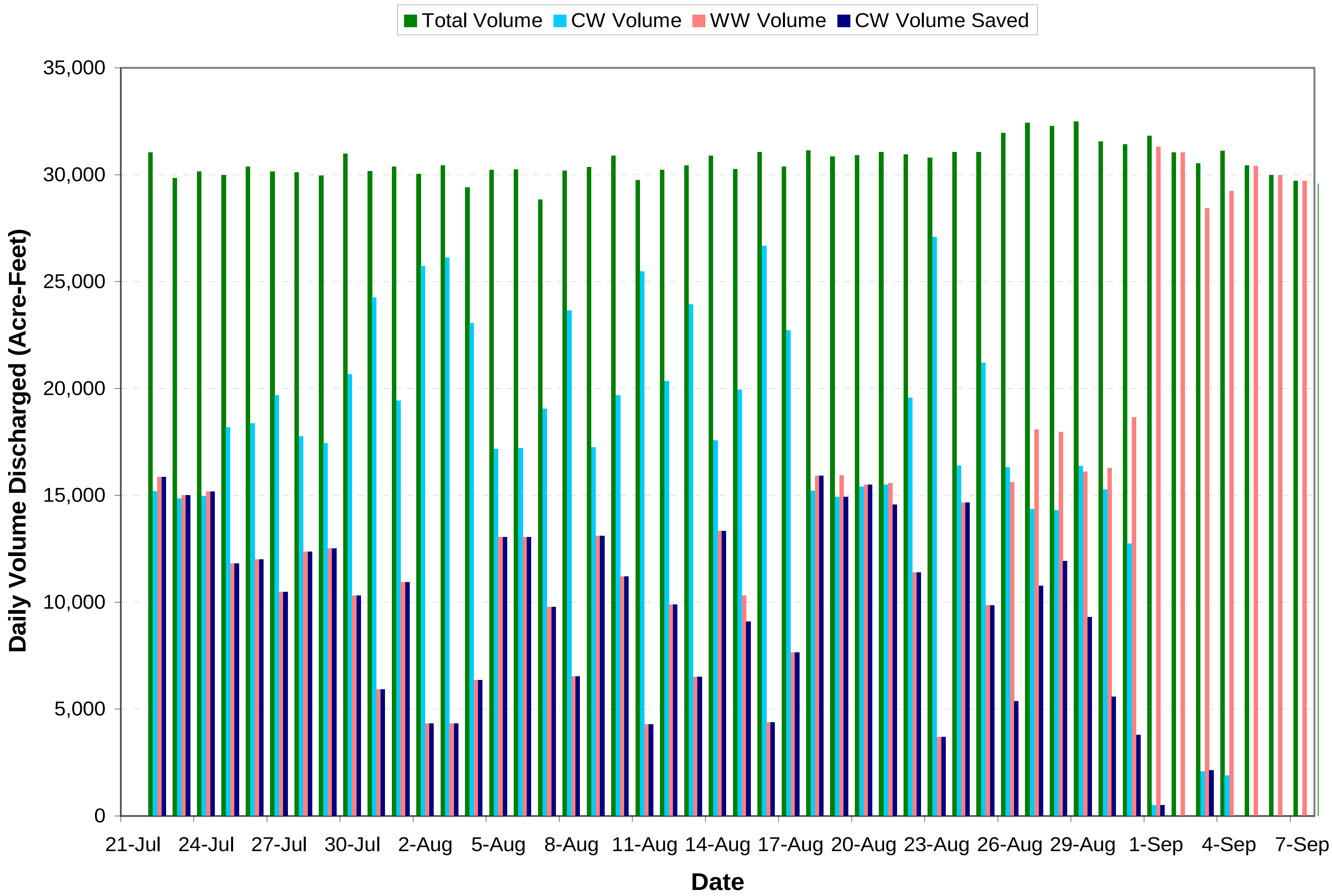


Figure 7.2. Potential savings of optimal coldwater habitat in Lake Sakakawea over the period July 22, to September 7, 2005 due to implementation of short-term water quality management measures at Garrison Dam. (Note: No water meeting optimal coldwater habitat criteria was discharged through Garrison Dam from September 8, to September 30, 2005, based on monitoring of dynamic water quality conditions in the five penstocks.)

7.4 CHANGES IN THE WATER QUALITY CONDITIONS OF THE WATER DISCHARGED THROUGH GARRISON DAM DUE TO THE IMPLEMENTATION OF SHORT-TERM WATER QUALITY MANAGEMENT MEASURES

7.4.1 WATER TEMPERATURE

The temperature of water discharged through Garrison Dam was taken to be the water temperature measured in the raw water loop in the powerhouse or the flow-weighted average temperature of water drawn from the five individual penstocks. Figure 7.3 plots the hourly temperature of the water discharged through Garrison Dam during the period July 21 through September 30 for 2003, 2004, and 2005. Figure 7.3 indicates that median temperature of the water discharged through Garrison Dam in 2005 was about 2°C warmer than the water temperatures measured in 2003 and 2004. Also, the variability of daily water temperatures was less in 2005 than in 2003 and 2004 (Figure 7.3). On average, minimum daily water temperatures in 2005 were 2 to 4°C warmer and maximum daily water temperatures were similar, and in some cases lower, than those measured in 2003 and 2004. The observed changes in the 2005 temperatures of the water discharged through Garrison Dam are attributed to the implementation of the short-term water quality measures in 2005. The implemented water quality management measures, particularly the trash-rack plywood barriers, restricted the withdrawal of colder near-bottom water from Lake Sakakawea and moderated the temperature of the water discharged through Garrison Dam.

7.4.2 DISSOLVED OXYGEN

The dissolved oxygen concentration measured in the raw water loop in the powerhouse or the flow-weighted average dissolved oxygen concentration of water drawn from the five individual penstocks was used to determine the dissolved oxygen concentration of water discharged through Garrison Dam. Figure 7.4 plots the hourly dissolved oxygen concentrations of the water discharged through Garrison Dam during the period July 21 through September 30 for 2003, 2004, and 2005. Dissolved oxygen concentrations occurring from July through late-August were similar in all 3 years (Figure 7.4). From late-August to the end of September dissolved oxygen concentrations in 2005 exhibited less diurnal fluctuation, with daily minimum values about 2 mg/l higher than those occurring in 2003 and 2004 (Figure 7.4). Daily maximum dissolved oxygen values during this period were similar in all 3 years (Figure 7.4). The observed differences in the 2005 dissolved oxygen concentrations of the water discharged through Garrison Dam are attributed to the implementation of the short-term water quality measures in 2005.

Near-bottom hypolimnetic dissolved oxygen levels in Lake Sakakawea near Garrison Dam typically degrade to below 5 mg/l by September. The restriction of the withdrawal of near-bottom water from Lake Sakakawea during this period due to the implementation of the short-term water quality management measures improved dissolved oxygen levels in the water discharged through Garrison Dam in September. As indicated in Figure 7.1, 69 percent of the minimum flow discharged in September was passed through penstocks 2 and 3 with the modified trash racks. Eighty percent of the maximum flow during September was passed through penstocks 1, 2, 3, and 4 – the penstocks with modified trash racks or lowered head gates (Figure 7.1). During September of 2003 and 2004 minimum, daily dissolved oxygen concentrations associated with minimum discharges from Garrison Dam were below North Dakota's water quality standard of 5 mg/l (Figure 7.4). The minimum daily dissolved oxygen levels in the water discharged through Garrison Dam remained above 5 mg/l in 2005 (Figure 7.4).

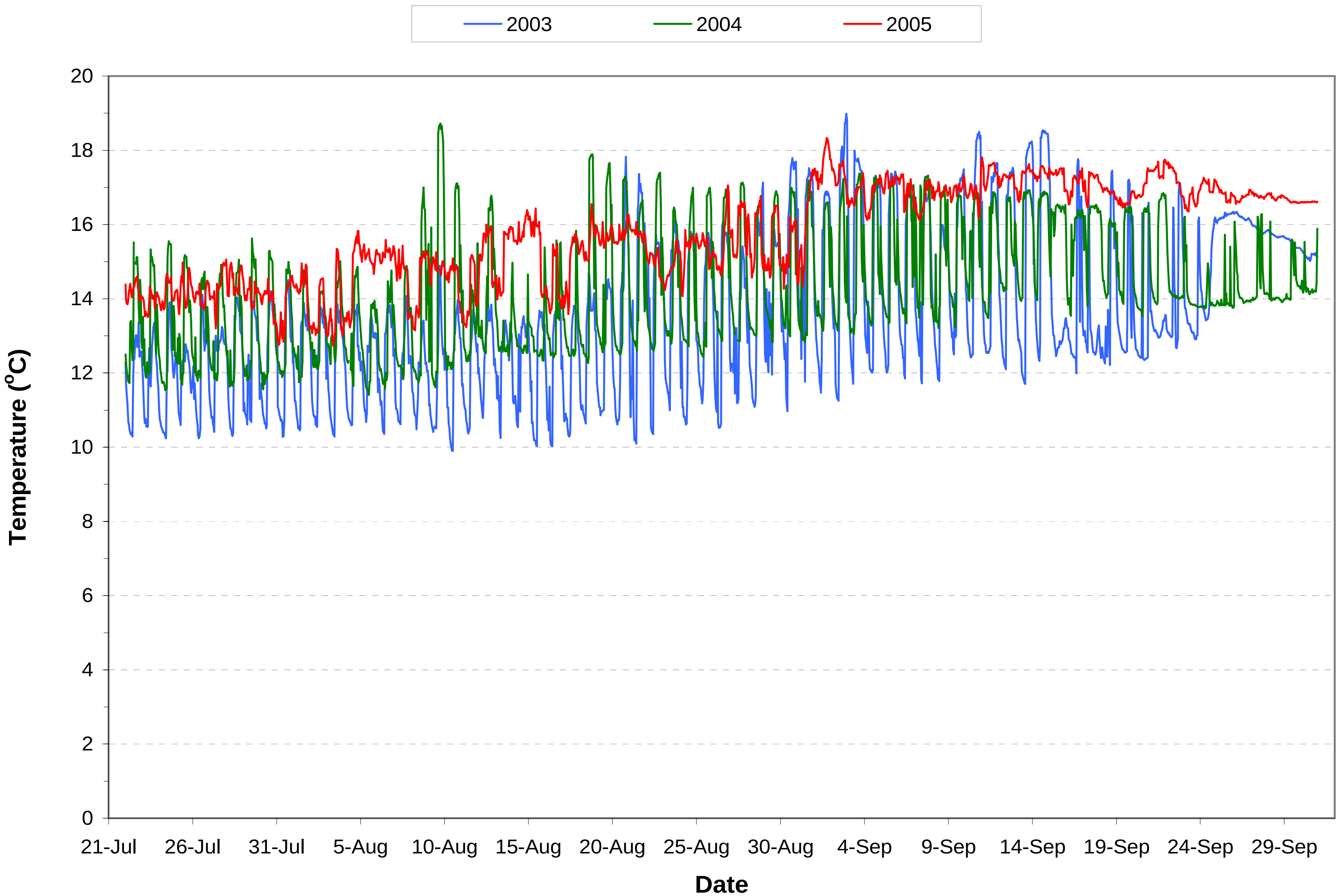


Figure 7.3. Temperature of water discharged from Garrison Dam during the period July 22 through September 30 in 2003, 2004, and 2005.

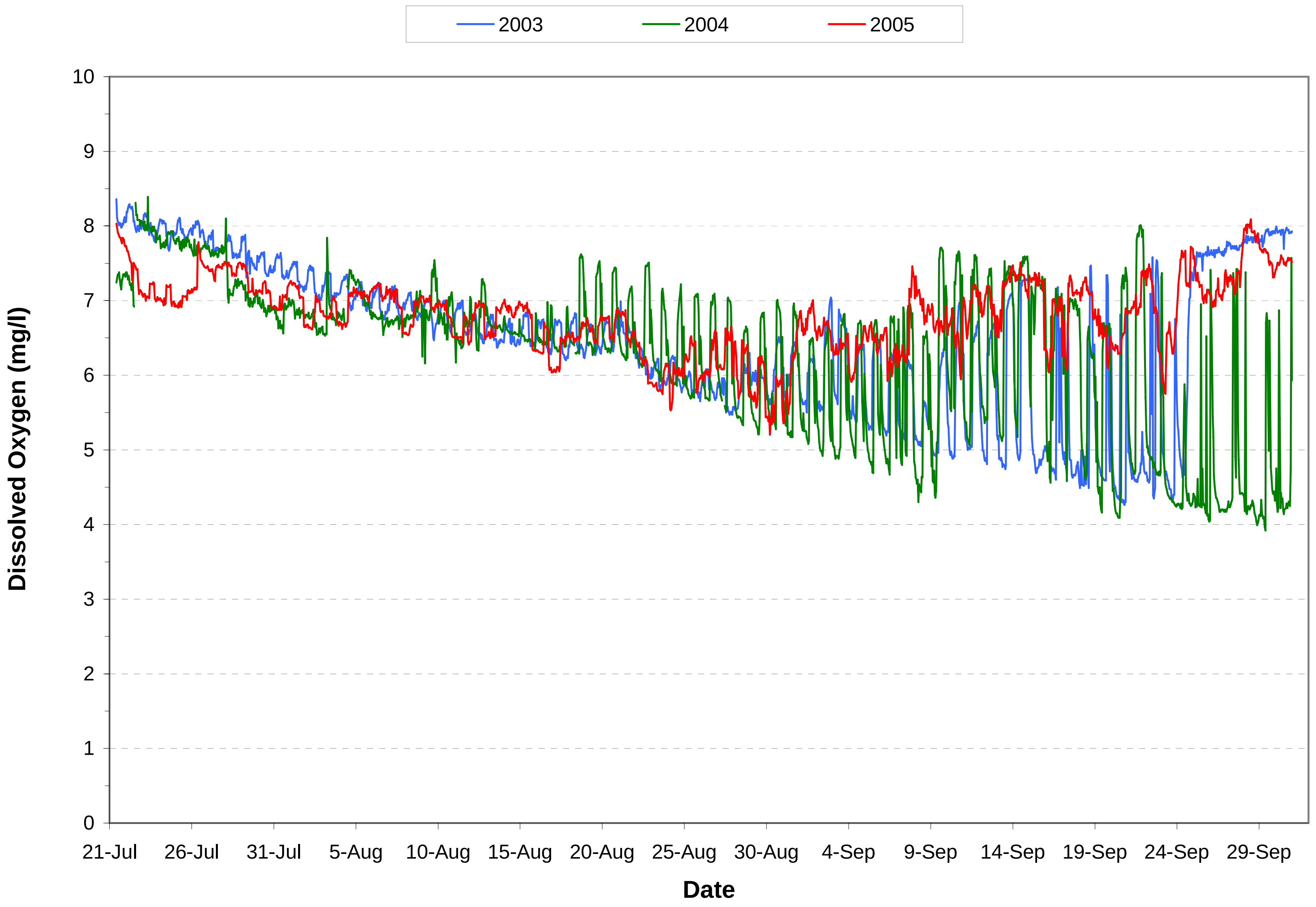


Figure 7.4. Dissolved oxygen concentration of water discharged from Garrison Dam during the period July 22 through September 30 in 2003, 2004, and 2005.

7.5 EFFECT OF IMPLEMENTED MEASURES ON WATER QUALITY IN THE MISSOURI RIVER DOWNSTREAM OF GARRISON DAM

(Note: A downstream temperature analysis was conducted by the North Dakota Game and Fish Department and transmitted via memorandum to the Omaha District USACE (Hendrickson Comm., 2006). The following paragraphs and figures were extracted from the prepared Memorandum.)

Water temperature data collected along the Missouri River downstream of Garrison Dam during the period June 1 through September 30, 2005 were compiled from four sources: 1) Corps data collected at the Garrison power house (RM 1389); 2) data collected at the Stanton-GRE power plant (RM1372); 3) data collected at the Heskett-Basin power plant (RM1319); and 4) data collected by temperature loggers installed by the North Dakota Game and Fish Department (NDFGD) at Burnt Creek (RM 1322), Fox Island (RM1312), Beaver Bay (RM 1259), and the Rivery (RM 1252). Water temperatures were cooler in the Garrison Dam Talirace and warmed going downstream (Figures 7.5 and 7.6). Water temperatures at the Heskett-Basin power plant were higher than those measured at Burnt Creek and Fox Island, which can be explained by the location of the temperature loggers and Heskett-Basin. The NDGFD installed temperature loggers in the main channel and the Heskett-Basin intake is on the side channel of the river, influenced by Square Butte Creek. Temperatures at Beaver Bay, the Rivery and Heskett-Basin were not significantly different from each other or the ambient air temperature at Bismarck. In addition, air and water temperatures at all locations from Burnt Creek downstream exhibited a strong correlation ($R > 0.74$ for all comparisons). Temperatures at Fox Island and Burnt Creek were lower than those downstream, but correlated well ($R=0.99$) and were not significantly different from each other. These correlations and tests for differences suggest that water temperatures in the lower river are dependent upon air temperature, while water temperatures in the Garrison Dam Tailrace and Stanton areas are independent of air temperature. Thus, the temperature of the water discharged from Garrison Dam (RM 1389) effects the ambient water temperature in the Missouri River downstream to Stanton (RM 1372). The influence of the temperature of the water discharged from Garrison Dam does not extend to Brunt Creek (RM 1322) as the ambient water temperature of the Missouri River at this location is largely dependent on ambient air temperature.

On July 20, 2006, the installation of the plywood barriers on the trash racks in front of penstocks 2 and 3 was completed and it was suspected that this would increase water temperatures in the Missouri River downstream of Garrison Dam, especially in the upper reaches which are inhabited by cold water fish species. To evaluate the potential increase in water temperatures, water temperature data collected at the Garrison Dam Tailrace and Stanton-GRE during the period July 21 through September 30 in 2004 and 2005 were compared. Water temperatures at the Garrison Dam Tailrace and Stanton were not influenced by air temperature (Correlation, $P > 0.10$), and water levels in Lake Sakakawea were similar for both years so differences in water temperatures are believed mostly due to the application of the plywood barriers to the trash racks. The average daily temperature for the week prior to and immediately after application of the plywood barriers increased significantly at the Garrison Dam Tailrace (t-test, $P = 0.002$), however the change was not significant at Stanton (t-test, $P = 0.06$) (Figure 7.7). Comparisons between the same time period in 2004 show no significant changes at Stanton (t-test, $P = 0.139$) or the Garrison Dam Tailrace (t-test, $P=0.310$). The average daily temperature for the July 21-September 30 period was significantly higher in 2005 than in 2004 for the Garrison Dam Tailrace and Stanton locations (LSD, $P < 0.05$) (Figure 7.8).

Although significant temperature increases occurred in the Missouri River at the Garrison Dam Tailrace and Stanton areas due to application of the application of the plywood barriers, water temperatures were still relatively cool with maximum daily temperatures reaching 17.2^{o}C (63^{o}F) in the tailrace and 20.6^{o}C (69^{o}F) at Stanton. These temperatures should not have severe impacts to the existing cold water fishery, and they may benefit the coolwater fisheries.

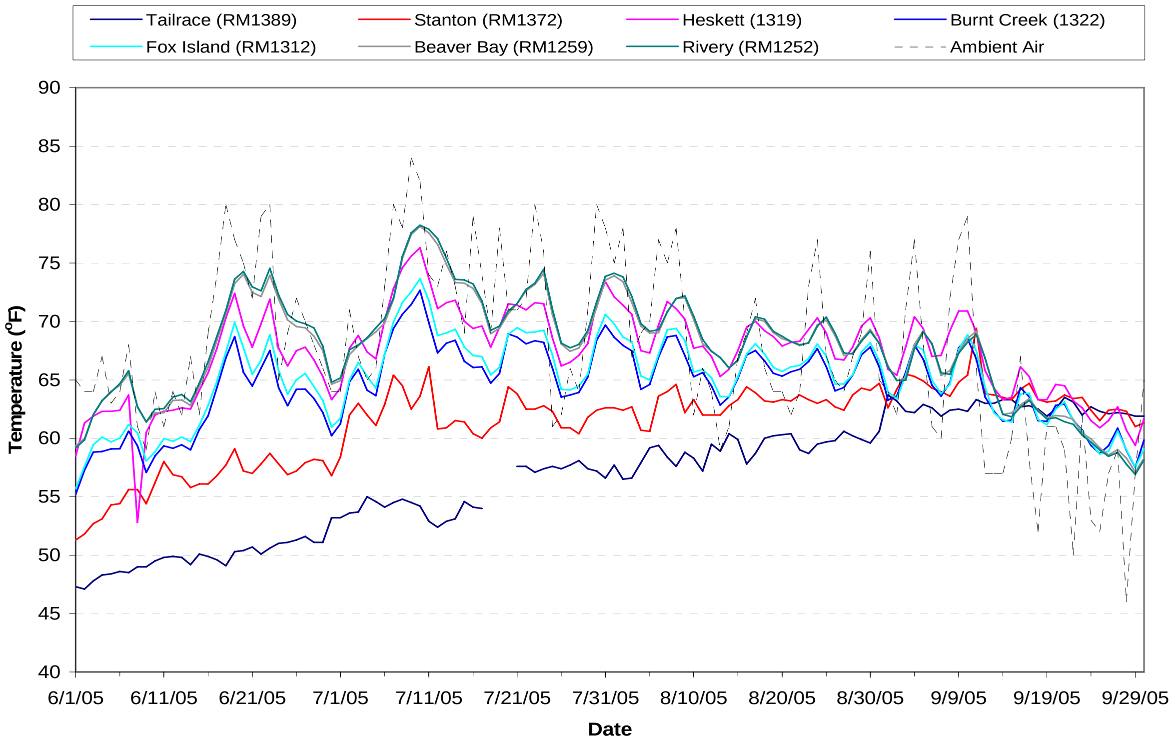


Figure 7.5. Mean daily water temperatures of the Missouri River downstream of Garrison Dam for the period June through September 2005.

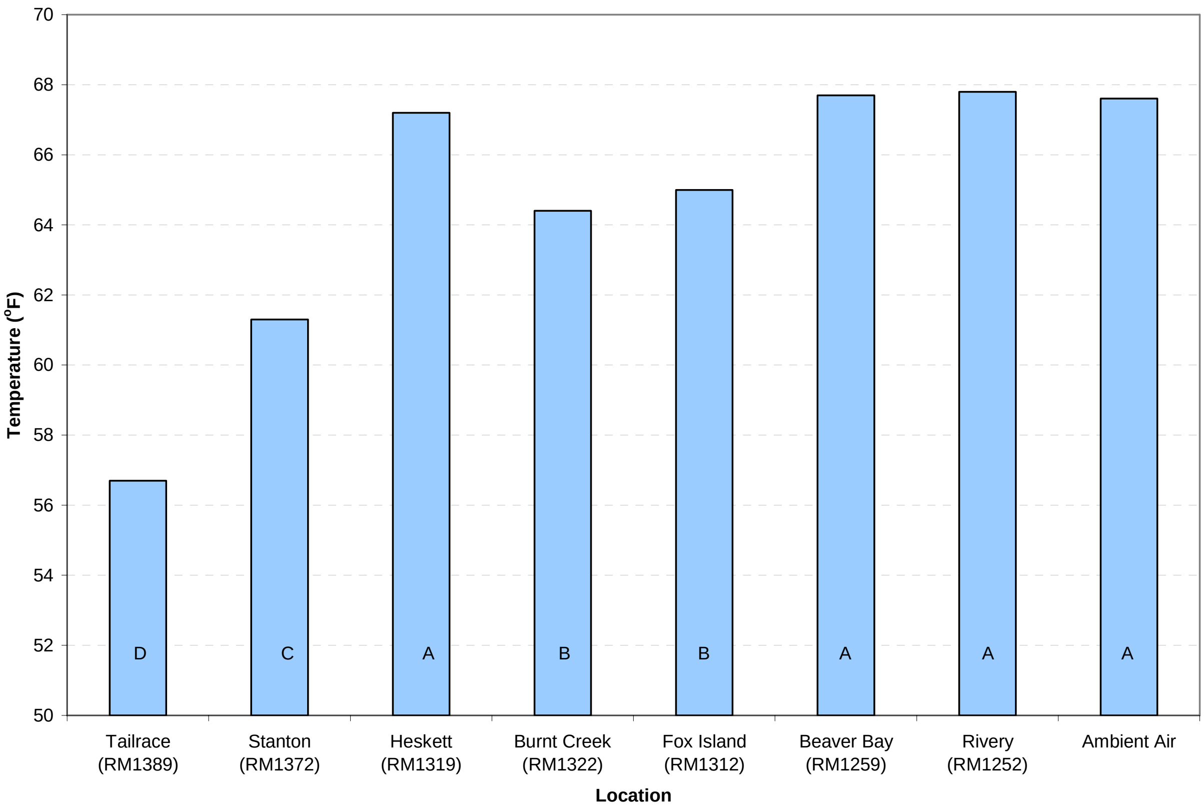


Figure 7.6. Mean water temperatures of the Missouri River downstream of Garrison Dam for the period June through September 2005. Bars with different letters are significantly different (LSD, p<0.05).

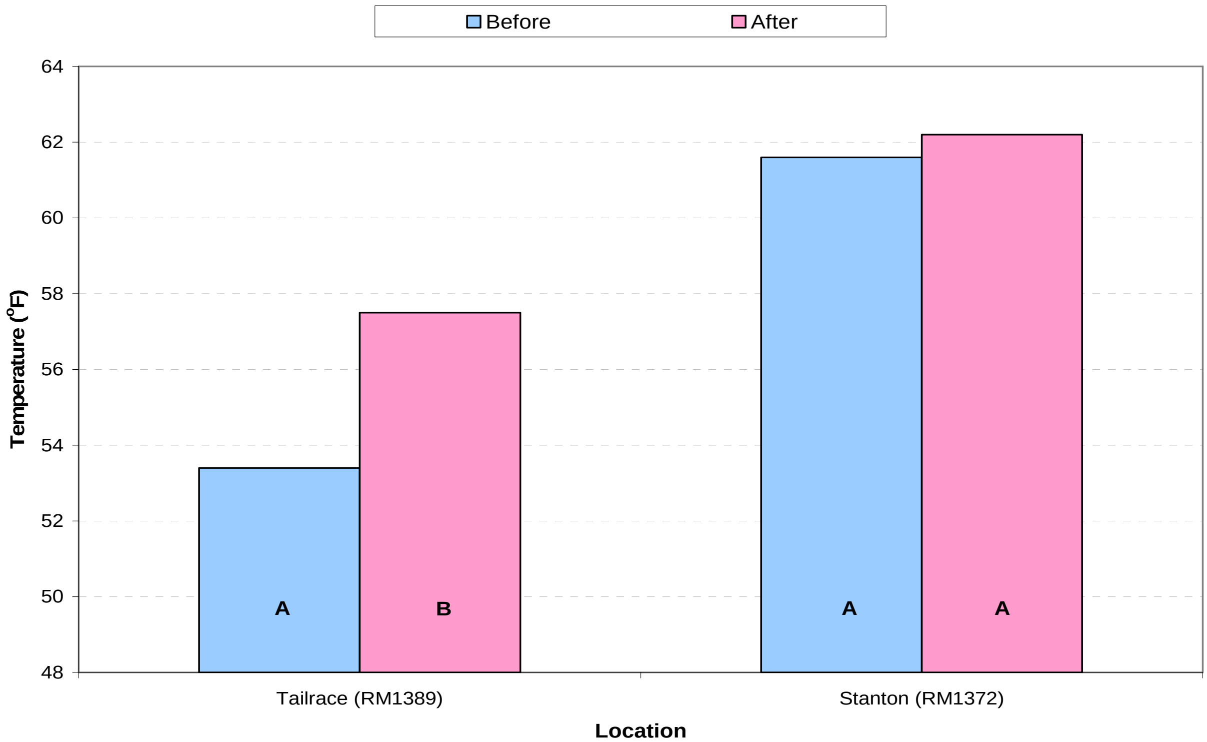


Figure 7.7. Mean water temperature of the Missouri River at the Garrison Dam Tailrace and Stanton one week before and after installation of the plywood barriers. Bars with different letters (within locations) are significantly different (t-test, $p < 0.05$).

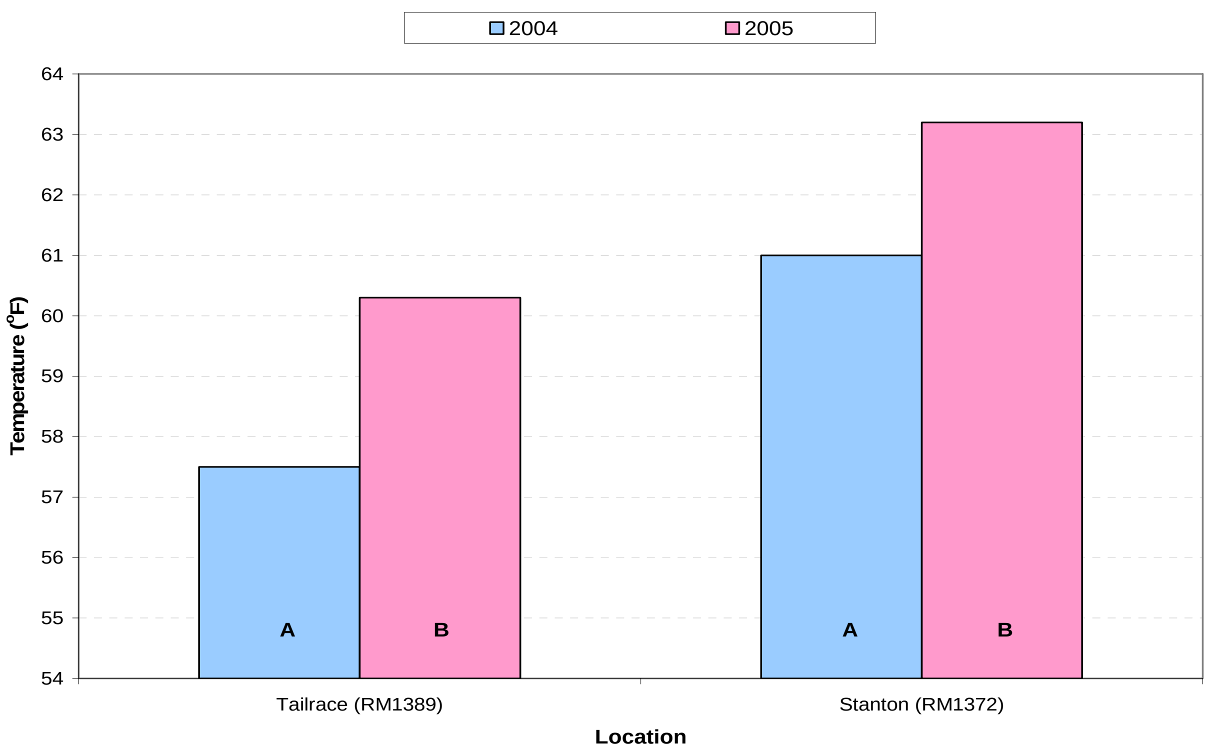


Figure 7.8. Mean water temperature of the Missouri River at the Garrison Dam Tailrace and Stanton in 2004 and 2005 during the period July 21 through September 30. Bars with different letters (within locations) are significantly different (t-test, $p < 0.05$).

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 EXISTING WATER QUALITY CONDITIONS

8.1.1 LAKE SAKAKAWEA

Overall, the existing water quality conditions monitored in Lake Sakakawea were good. However, a concern does exist regarding water temperature and dissolved oxygen conditions presently occurring in the lake under the low pool levels associated with the ongoing drought conditions. Water quality conditions under the current low pool levels (i.e., pool levels < 1825 ft-ms) appear to be limiting the occurrence of optimal coldwater habitat (i.e., temperature $\leq$ 15°C and dissolved oxygen $\geq$ 5 mg/l) in Lake Sakakawea. Water quality conditions in Lake Sakakawea vary significantly along the length of the lake, and strong thermal stratification occurs in the deeper area of the lake during the summer. Water quality monitoring indicates that the lacustrine zone of Lake Sakakawea is mesotrophic, while the riverine and transition zone of the lake are eutrophic to moderately eutrophic. The phytoplankton community of Lake Sakakawea is dominated by diatoms with only minor "blooms" of cyanobacteria.

8.1.2 WATER DISCHARGED THROUGH GARRISON DAM

With the exception of late summer, the water discharged through Garrison Dam exhibited good water quality. During September of 2003 and 2004, monitoring indicated that North Dakota's water quality standards criterion for dissolved oxygen of 5 mg/l was not met in the water discharged through Garrison Dam during minimum flow releases. This situation did not occur in 2005.

8.2 RESULTS OF IMPLEMENTING SHORT-TERM WATER QUALITY MANAGEMENT MEASURES ON WATER QUALITY CONDITIONS

8.2.1 LAKE SAKAKAWEA

No change in water quality conditions measured in Lake Sakakawea was discernable due to the implementation of the short-term water quality management measures. However, based on water quality monitoring of the water discharged through Garrison Dam, it appears that up to 379,390 acre-feet of water meeting optimal coldwater habitat criteria where prevented from being discharged through Garrison Dam and retained in Lake Sakakawea due to the implementation of the short-term water quality management measures.

8.2.2 MISSOURI RIVER BELOW GARRISON DAM

Implementation of the short-term water quality management measures warmed the water that was discharged through Garrison Dam in the late summer by 2 to 4°C. How far downstream the Missouri River this warming was detectable and any possible consequences have not been determined at this time. The implemented water quality management measures also had the effect of raising dissolved oxygen concentrations in the water discharged through Garrison Dam in late summer under minimum flow releases. Although the short-term water quality management measures were implemented to preserve coldwater habitat in Lake Sakakawea, they also had the probable benefit of preventing the State of North Dakota's water quality standards criterion for dissolved oxygen from being exceeded in the Missouri River immediately below Garrison Dam during late summer low flow releases.

8.3 MAINTENANCE OF COLDWATER HABITAT IN LAKE SAKAKAWEA

The most crucial period for the support of coldwater habitat in Lake Sakakawea is when the lake begins to cool in late summer. As the thermocline moves deeper, the volume of the coldwater hypolimnion continues to decrease while the expanding epilminion has not cooled enough to be supportive of coldwater habitat. At the same time, hypolimnetic dissolved oxygen concentrations are approaching their maximum degradation and low dissolved oxygen levels are moving upward from the lake bottom and pinching off coldwater habitat from below. This situation will continue to worsen until the epilimnion cools enough to be supportive of coldwater habitat and the lake eventually experiences fall turnover.

Two factors greatly influence the occurrence of coldwater habitat in Lake Sakakawea during late summer. These two factors are the near-bottom location for withdrawing water from Lake Sakakawea for discharge through Garrison Dam, and the volume of hypolimnetic water present in Lake Sakakawea. The near-bottom withdrawal of water impacts coldwater habitat in Lake Sakakawea by: 1) depleting the volume of the hypolimnion by discharging hypolimnetic water through Garrison Dam, 2) warming the hypolimnion by inducing mixing within the hypolimnion, and 3) causing interflows along the lake bottom that carries oxygen demanding materials and low dissolved oxygen water through the lake's lacustrine zone to the dam. The hypolimnetic volume impacts coldwater habitat in Lake Sakakawea by: 1) providing suitable thermal requirements for coldwater aquatic life, 2) providing assimilative capacity for absorbing oxygen demand while maintaining adequate levels of dissolved oxygen for aquatic life, and 3) buffering the affects of the bottom withdrawal. The affect of the near-bottom withdrawal on the occurrence of coldwater habitat in Lake Sakakawea increases as pool levels fall and the hypolimnetic volume decreases. Managing the bottom withdrawal and hypolimnetic volume can be used to some extent to enhance the occurrence of coldwater habitat in Lake Sakakawea.

8.4 PRELIMINARY IDENTIFICATION OF WATER QUALITY MANAGEMENT MEASURES THAT COULD BE IMPLEMENTED AT LAKE SAKAKAWEA TO IMPROVE COLDWATER HABITAT CONDITIONS

Preliminary indications are that optimal coldwater habitat begins to be stressed as pool levels fall below 1825 ft-msl and marginal coldwater habitat may begin to be stressed as pool levels fall below 1815 ft-msl. Maintaining pool levels at or above these elevations would help maintain coldwater habitat in Lake Sakakawea. The critical time for these pool levels to occur is in late spring/early summer when the hypolimnion is being established in the lake.

Implementation of management measures at Garrison Dam to allow water to be withdrawn from higher in-lake elevations help maintain coldwater habitat in Lake Sakakawea; especially when pool levels are drawn down during drought conditions. To help maintain coldwater habitat in Lake Sakakawea, consideration should be given to continue the short-term water quality management measures implemented at Garrison Dam in 2005 as long as the pool elevations remains below 1825 ft-msl. If maintaining dissolved oxygen levels above 5 mg/l in the Missouri River immediately below Garrison Dam during late summer minimum flow releases is deemed a concern, a more long-term application of these management measures should be considered.

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10 PLATES

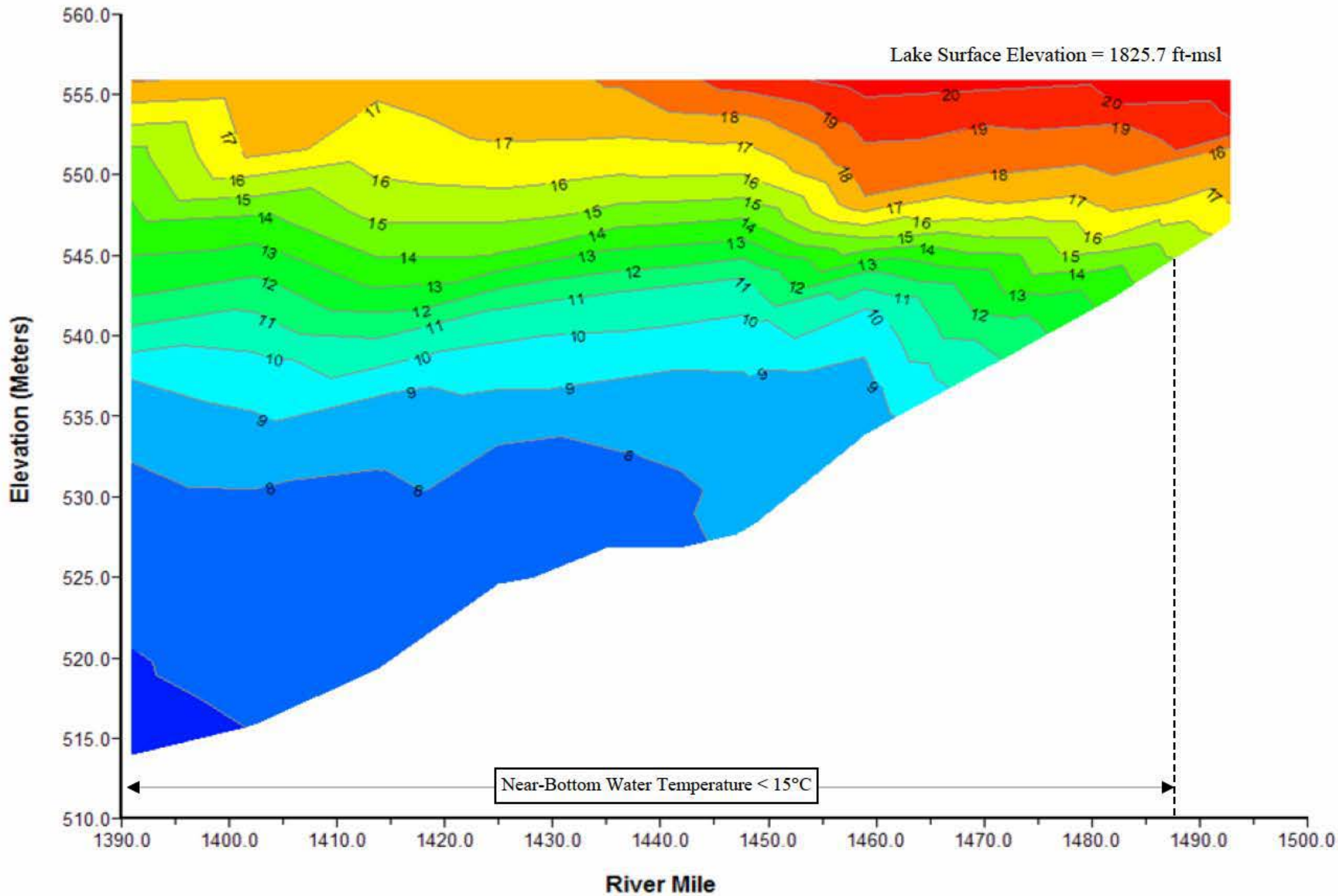

Plate 1. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 17-18, 2003.

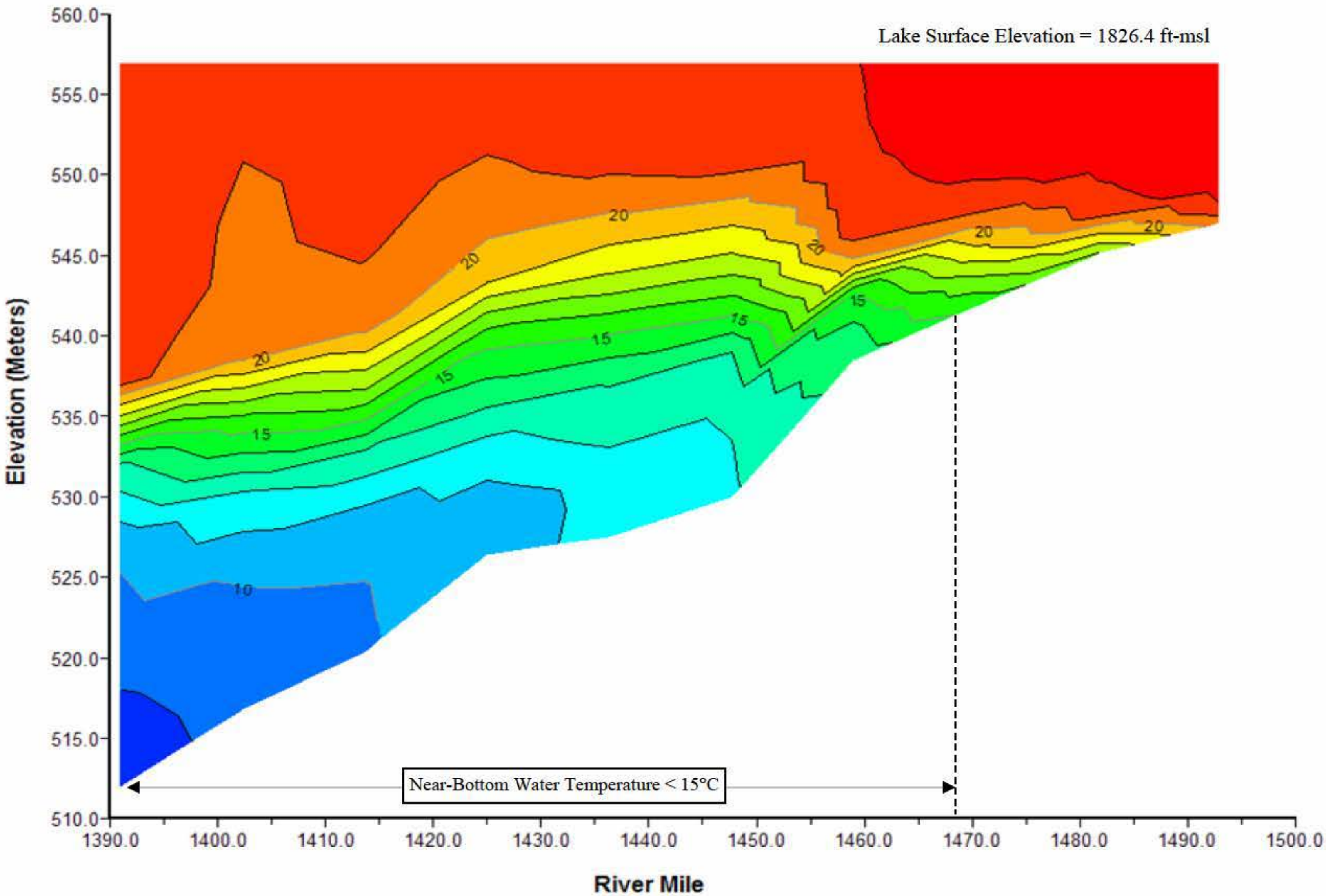

Plate 2. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 29-30, 2003.

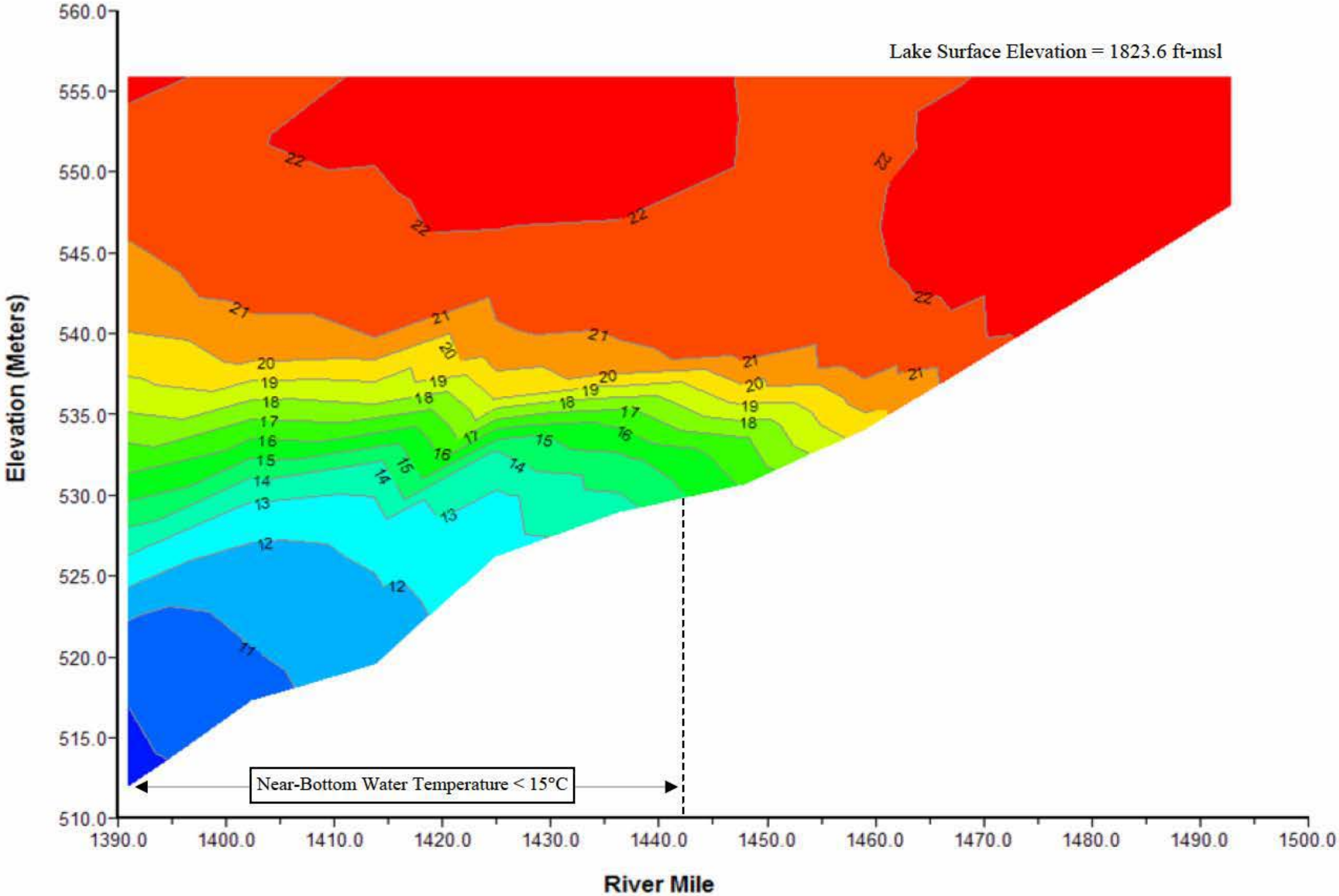

Plate 3. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, L7, and L8 on August 26-28, 2003.

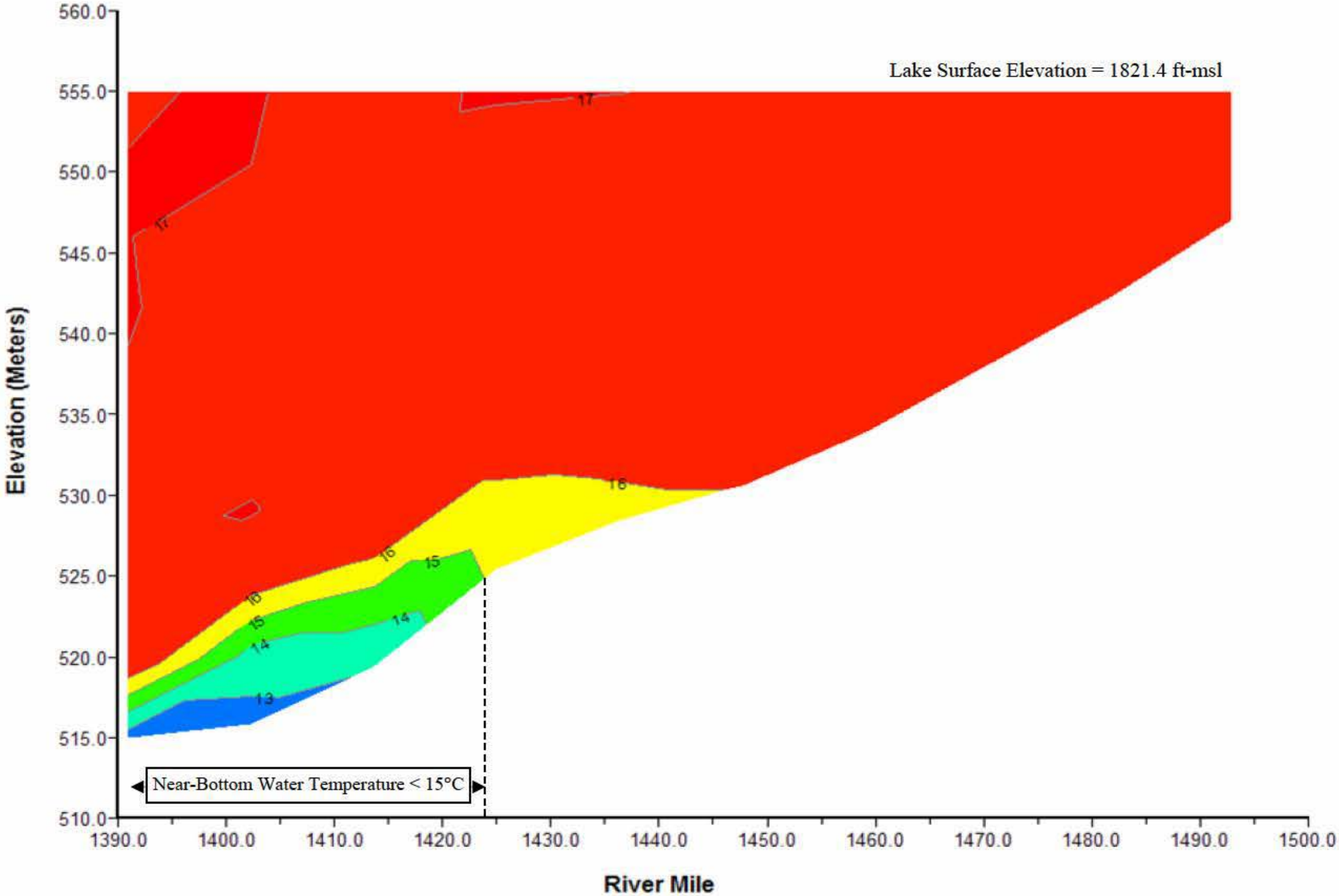

Plate 4. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, and L4 on September 23, 2003.

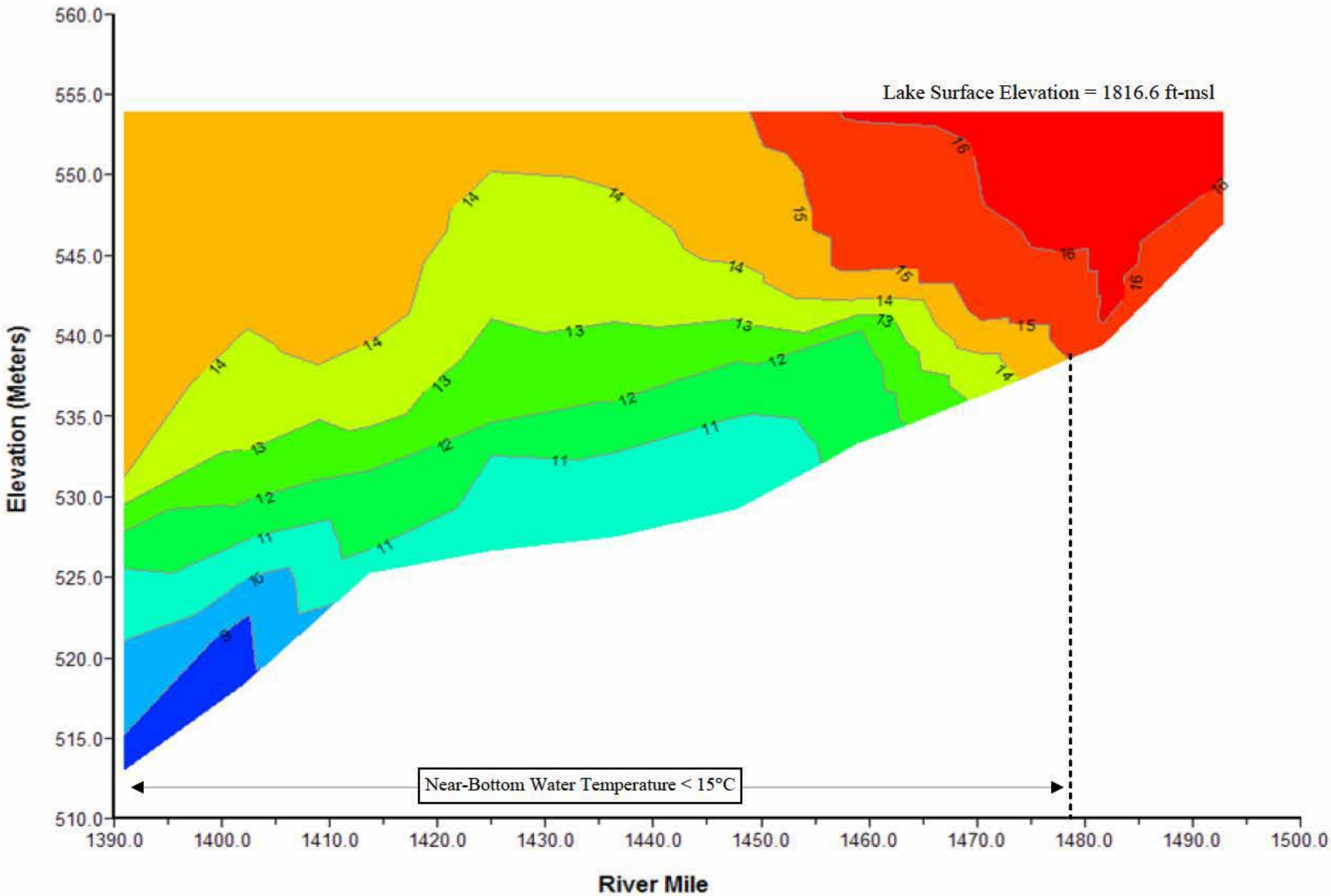

Plate 5. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 24-25, 2004.

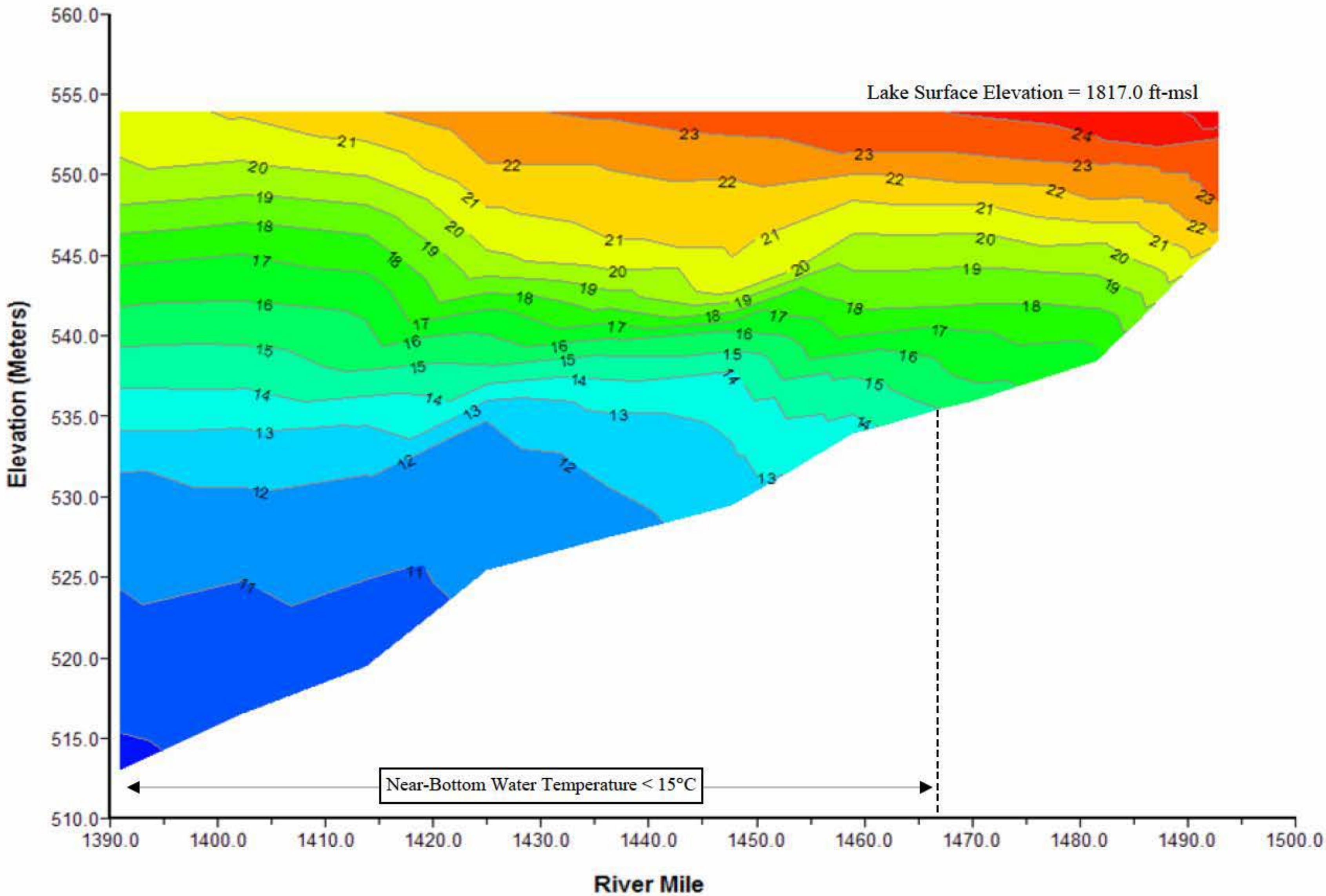

Plate 6. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 19, 2004.

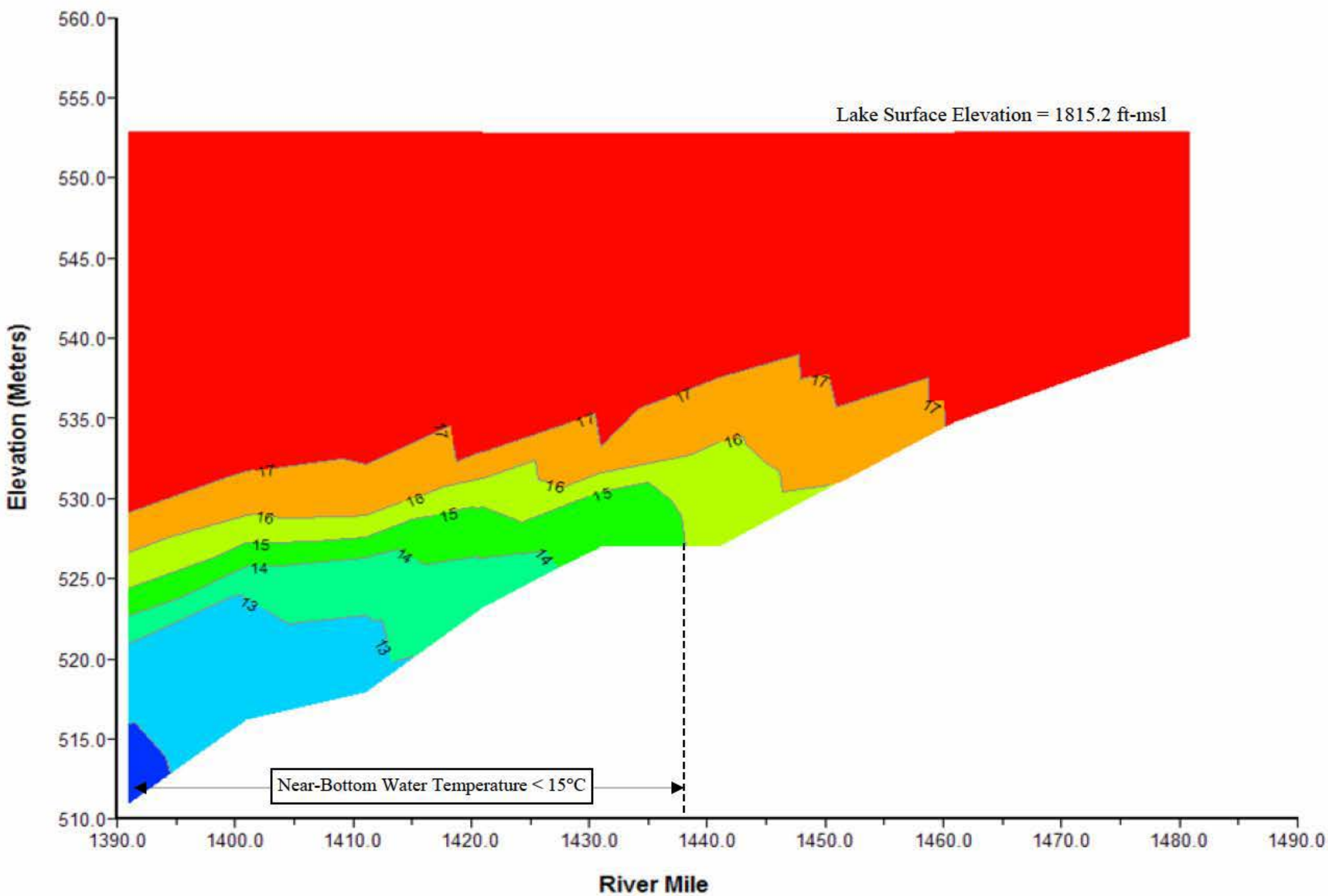

Plate 7. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 24-25, 2004.

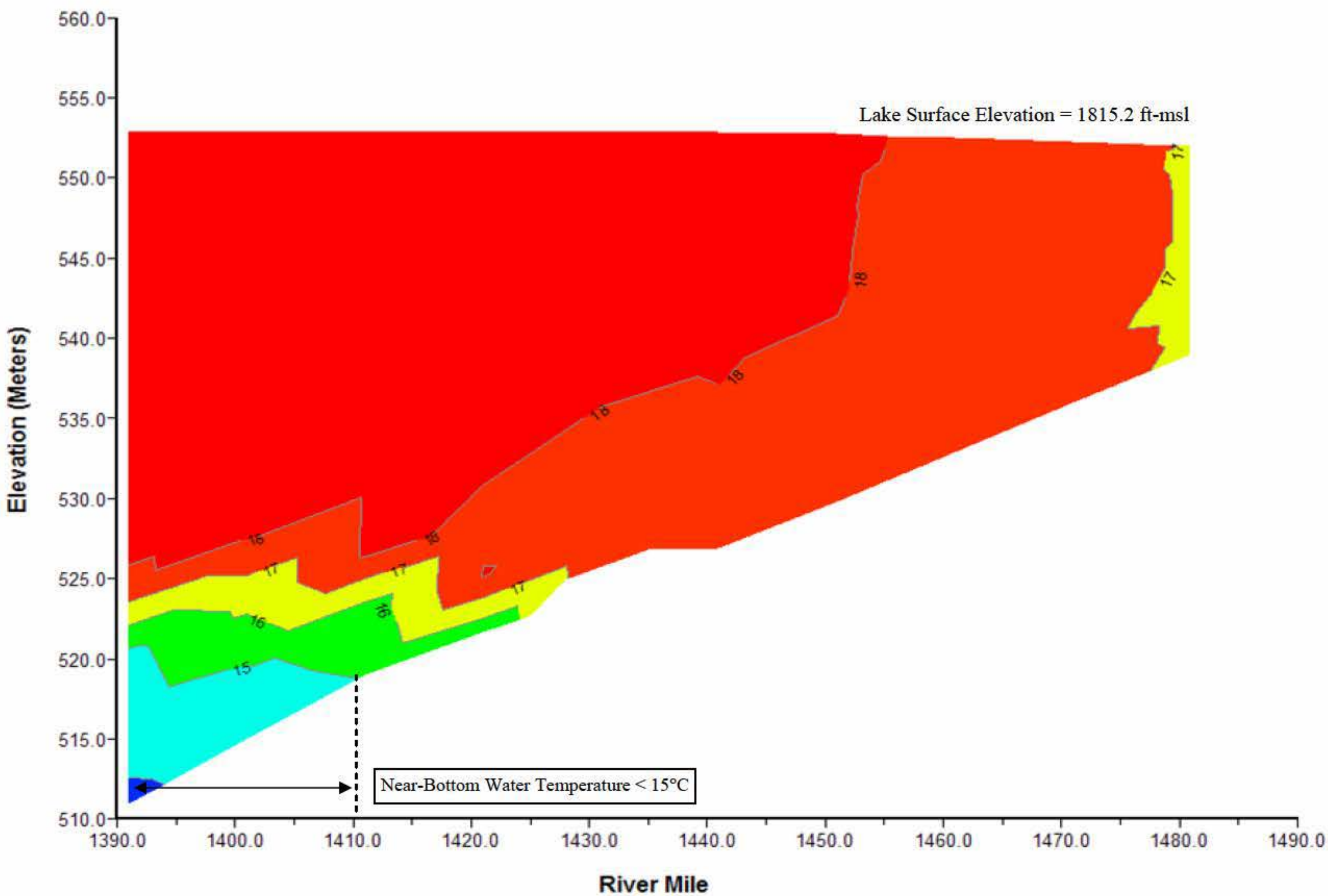

Plate 8. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 20-21, 2004.

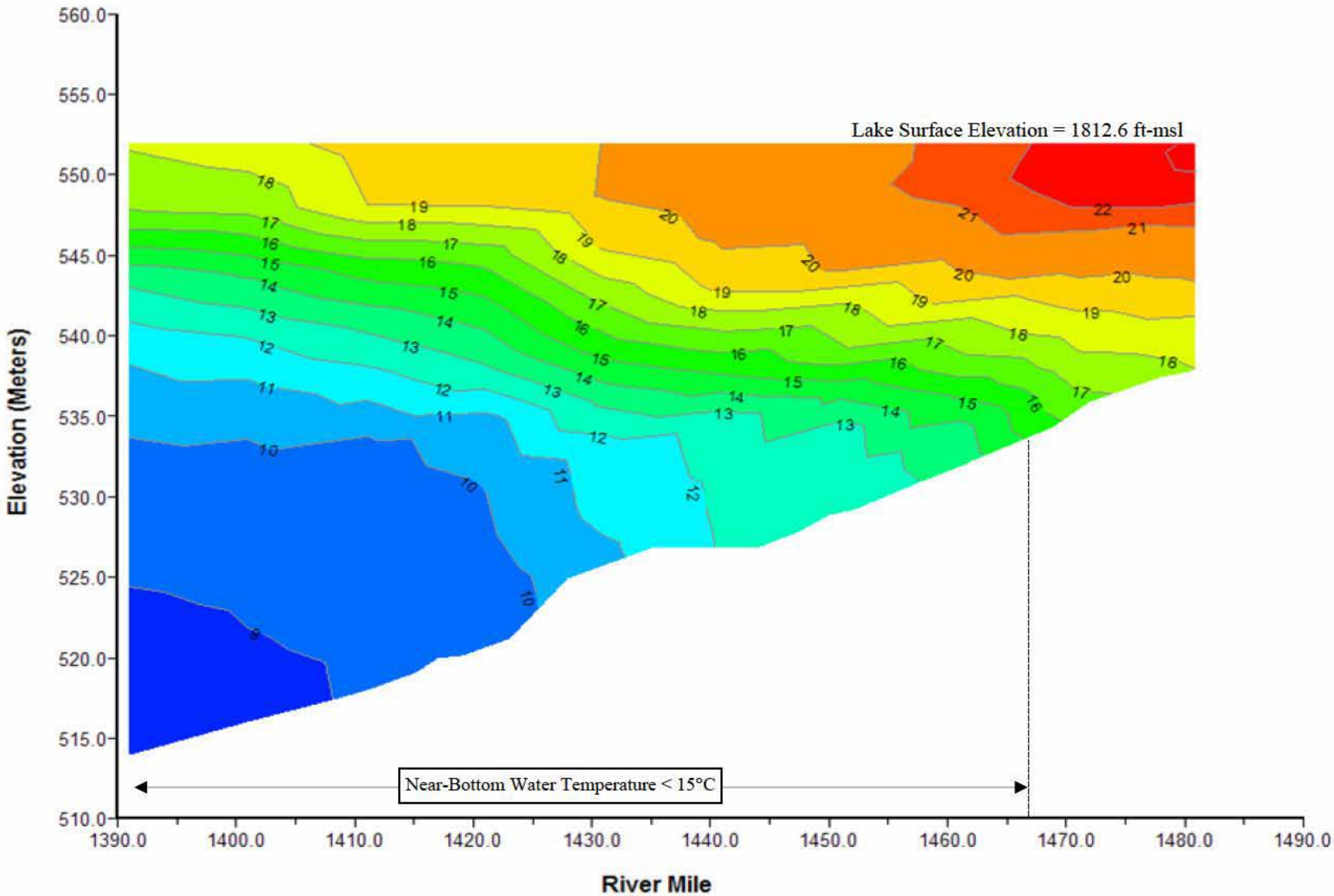

Plate 9. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L3, L5, and L7 on June 21-22, 2005.

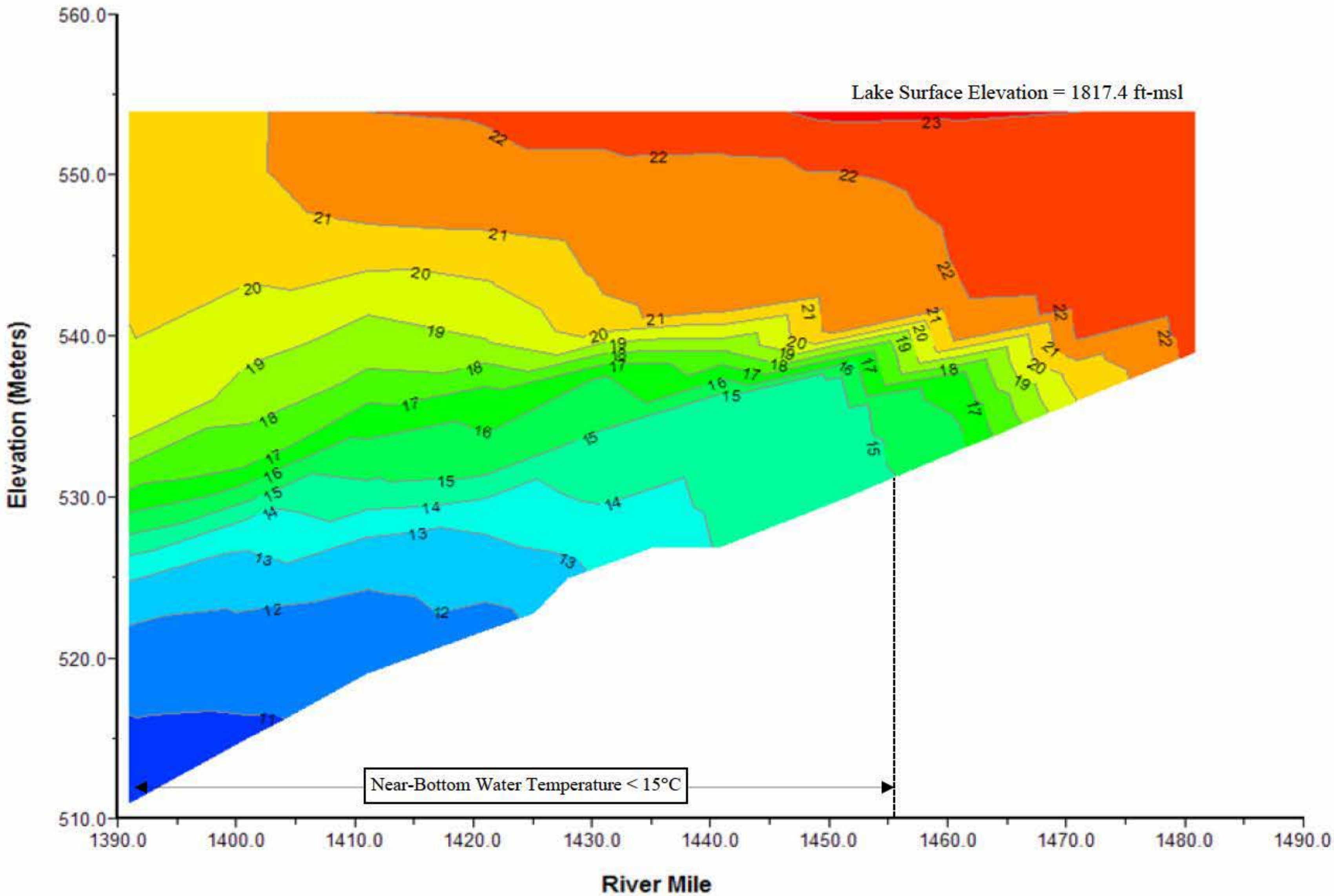

Plate 10. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L3, L5, and L7 on July 19-20, 2005.

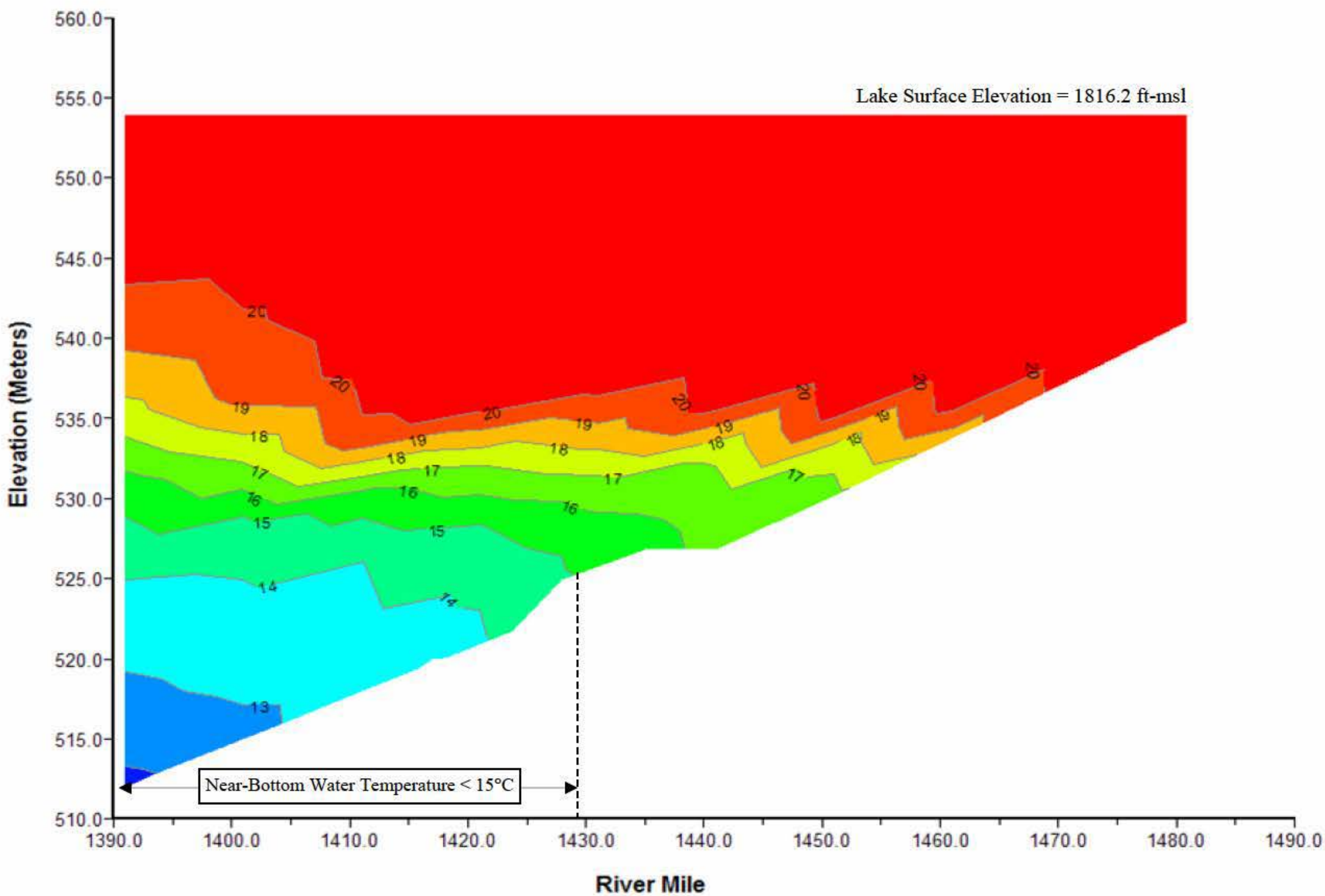

Plate 11. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L3, L5, and L7 on August 23-24, 2005.

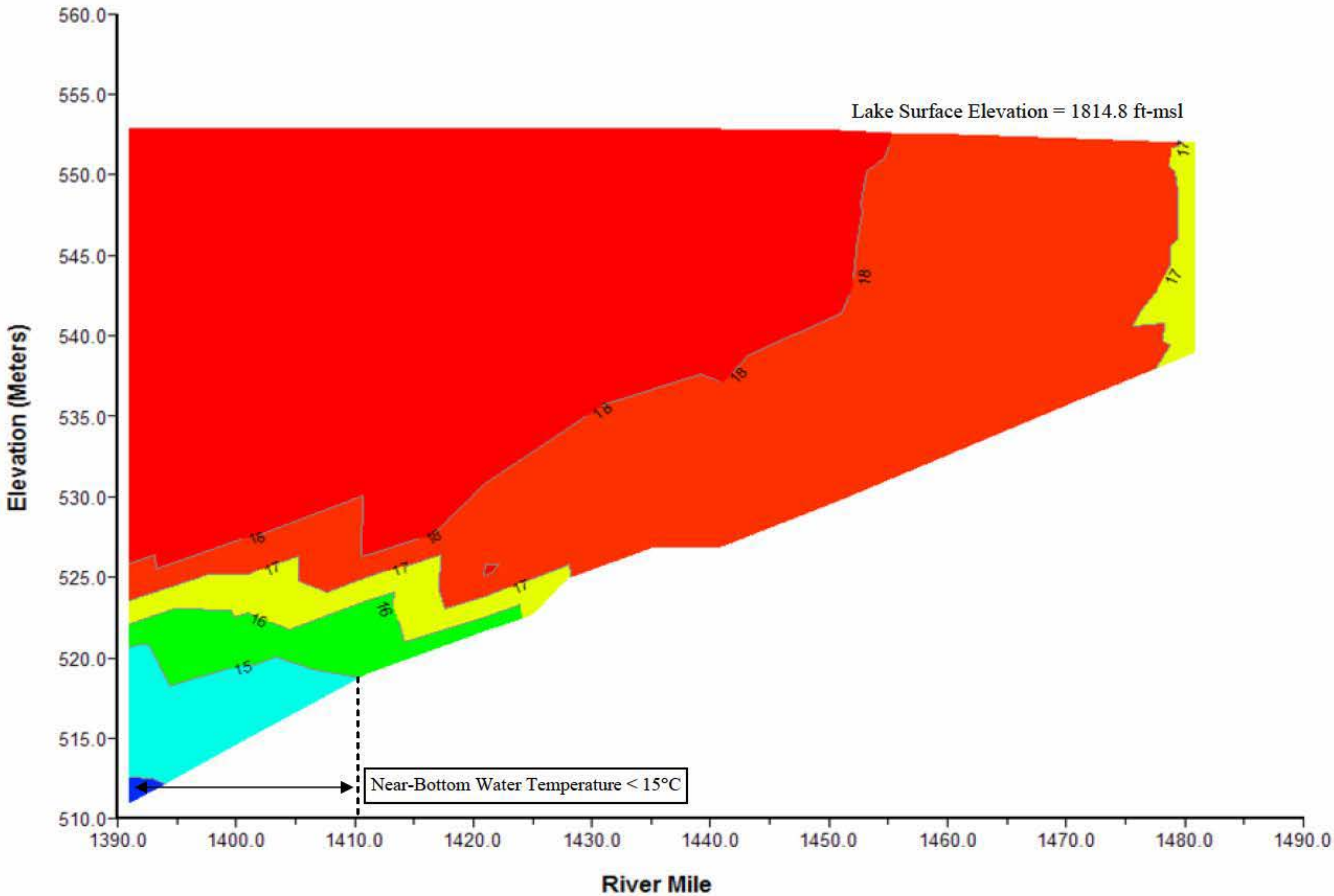

Plate 12. Longitudinal water temperature contour plot of Lake Sakakawea based on depth-profile water temperatures monitored at sites L1, L2, L3, L5, and L7 on September 19-20, 2005.

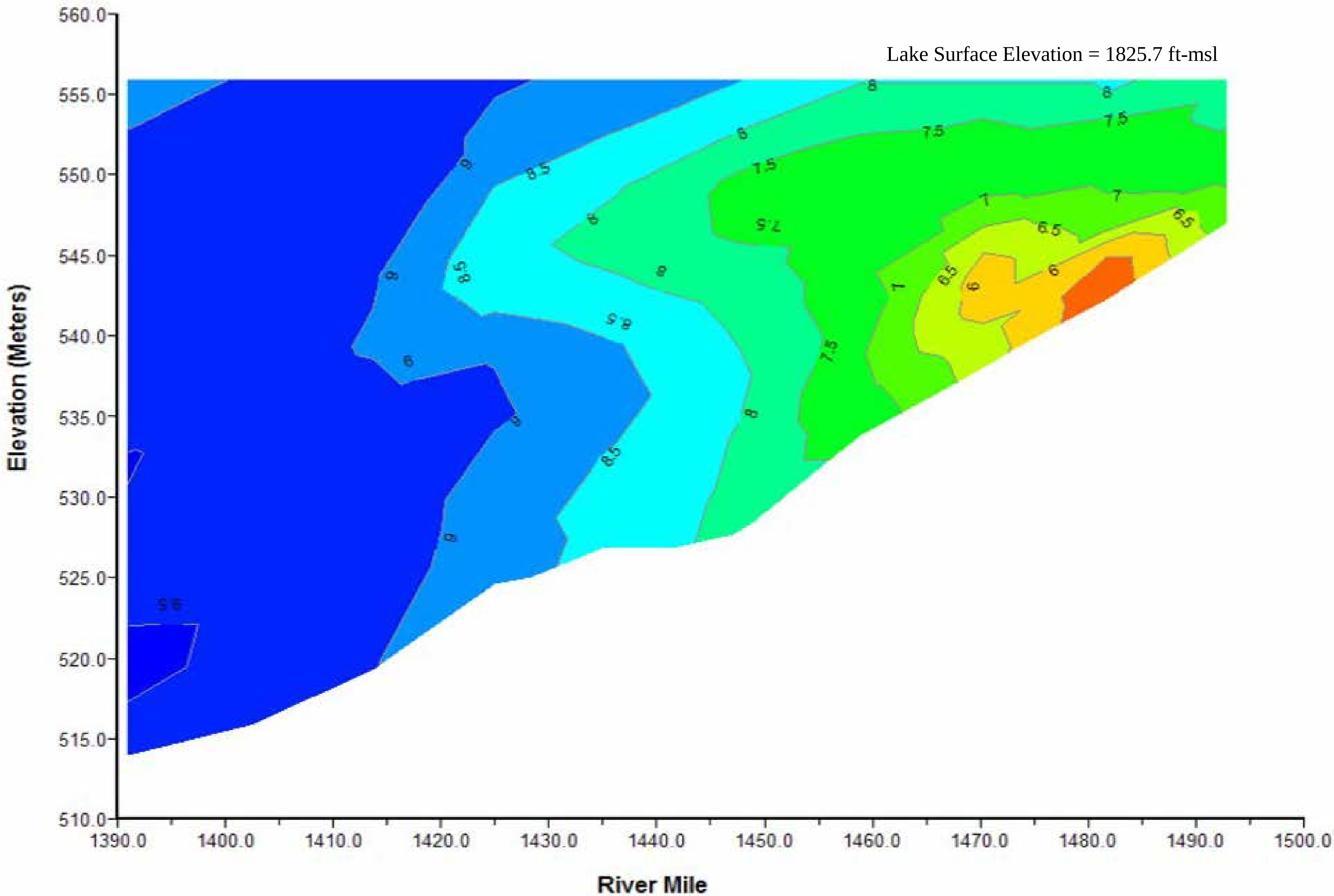

Plate 13. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 17-18, 2003.

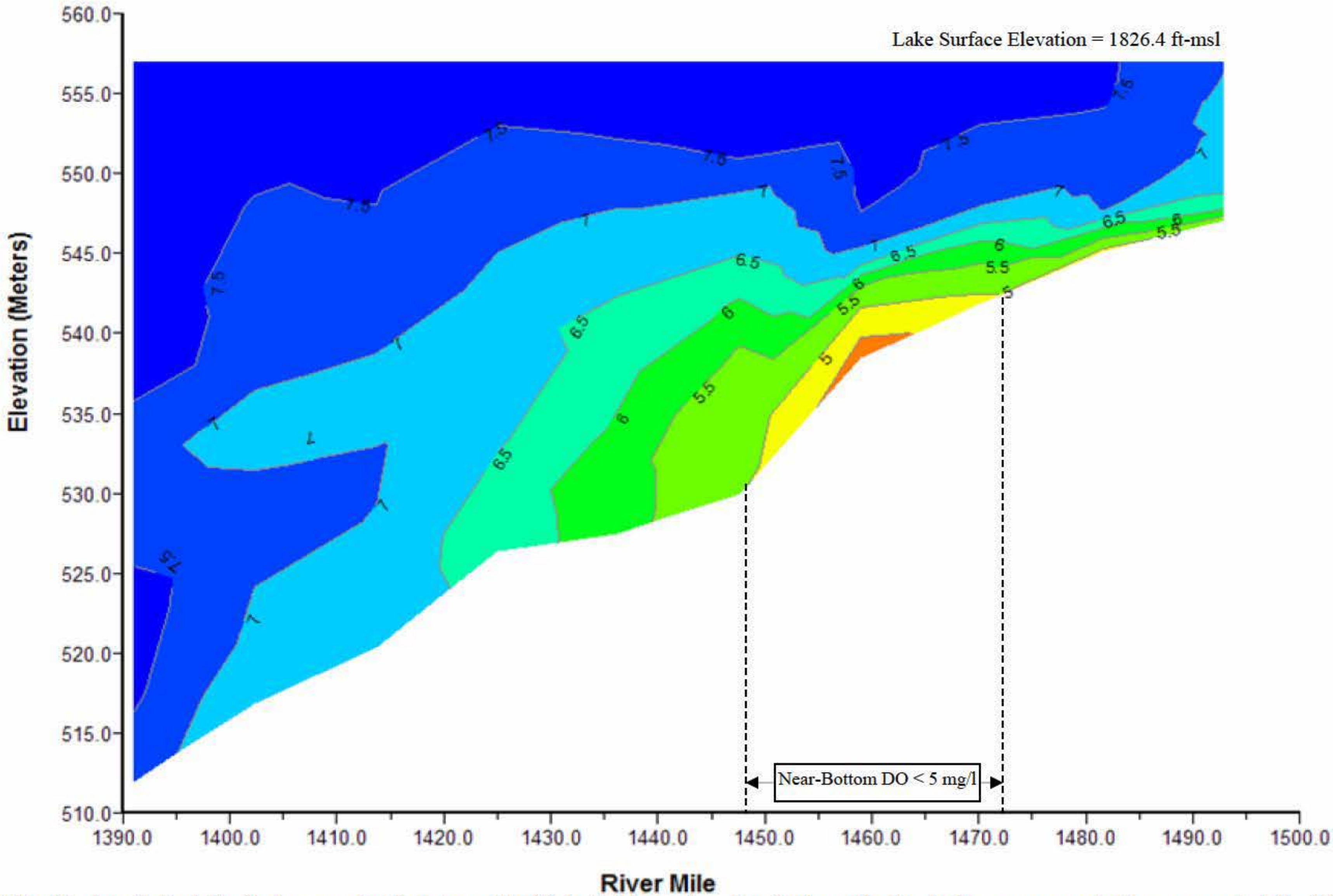

Plate 14. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 29-30, 2003.

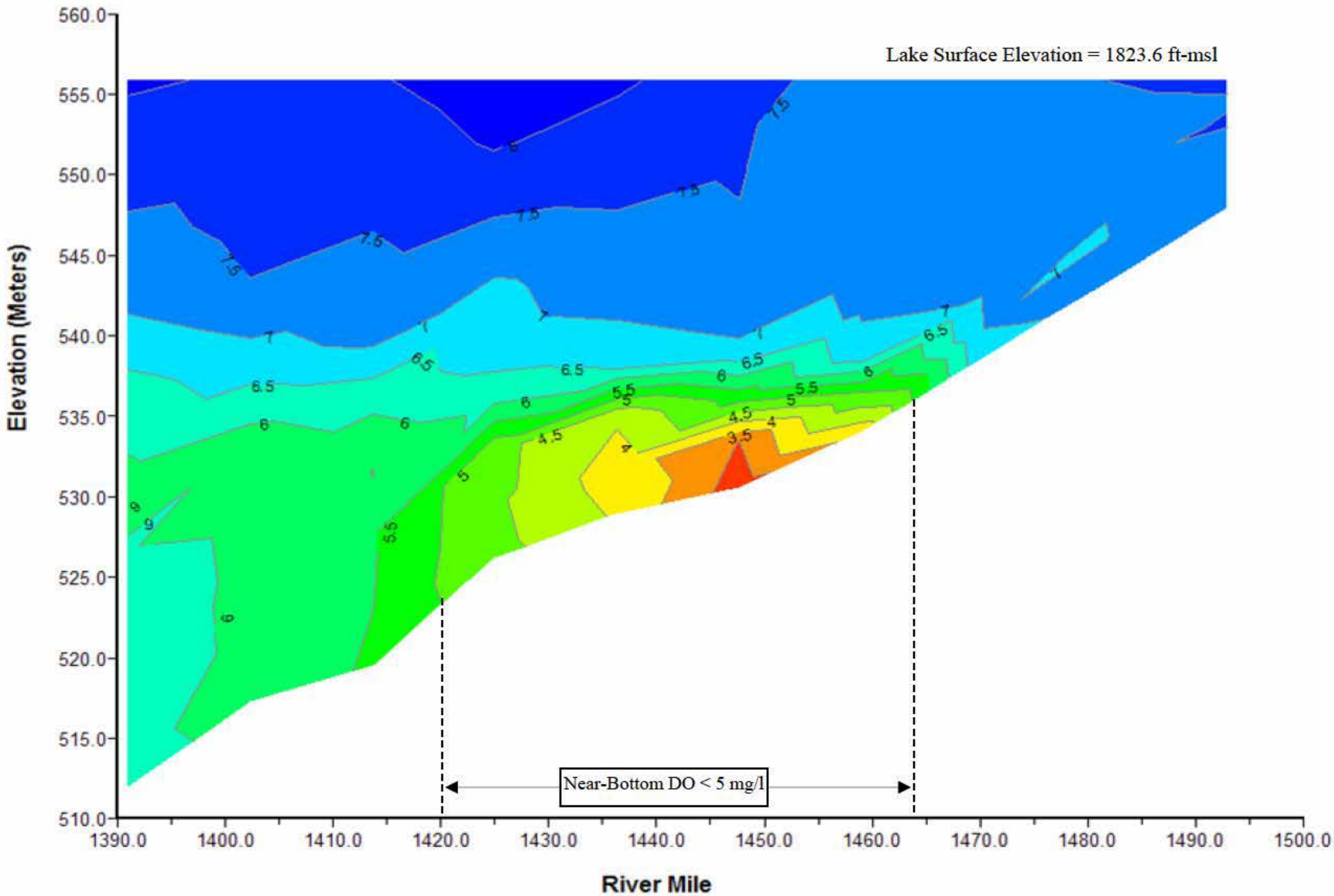

Plate 15. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on August 26-28, 2003.

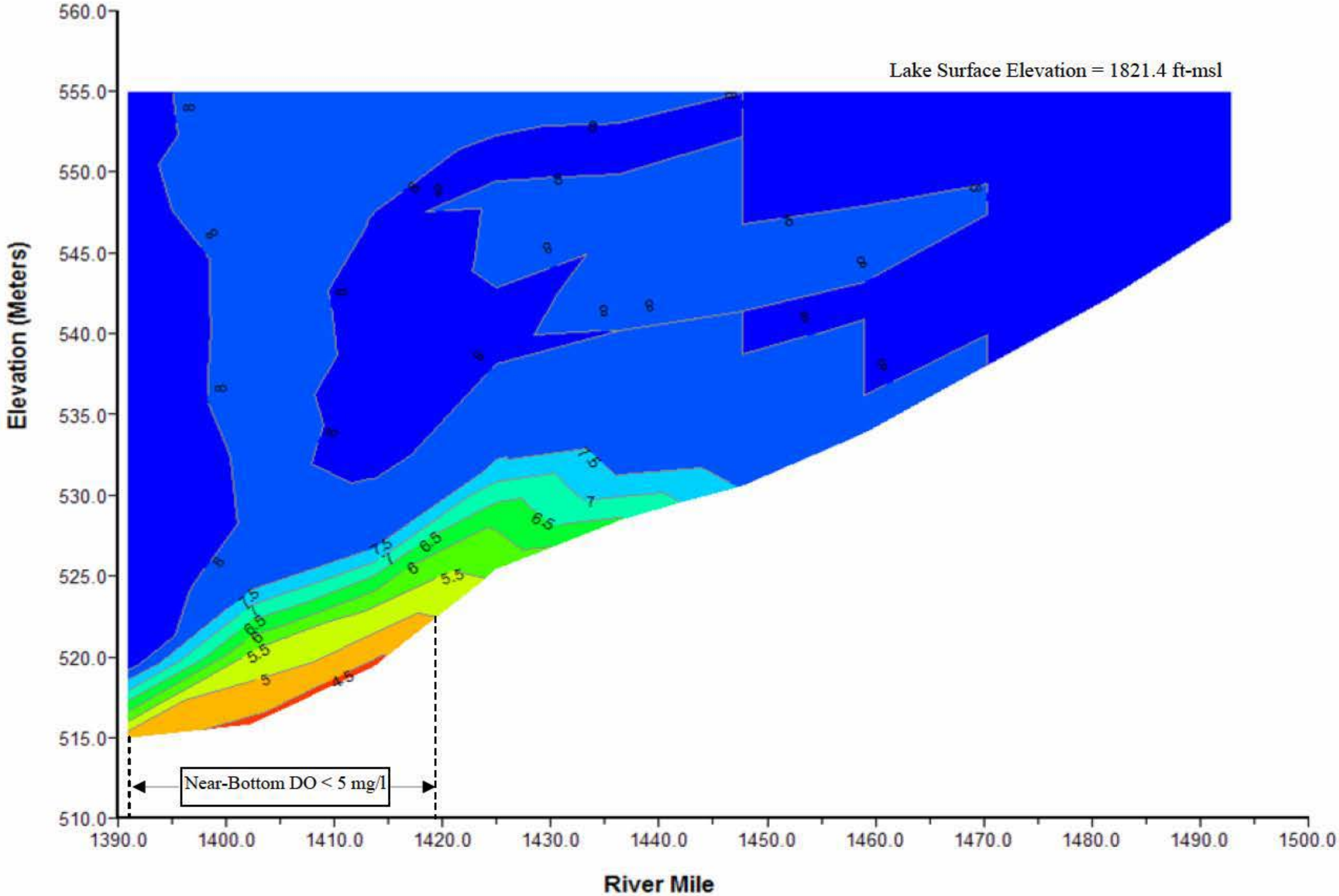

Plate 16. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, and L4 on September 23, 2003.

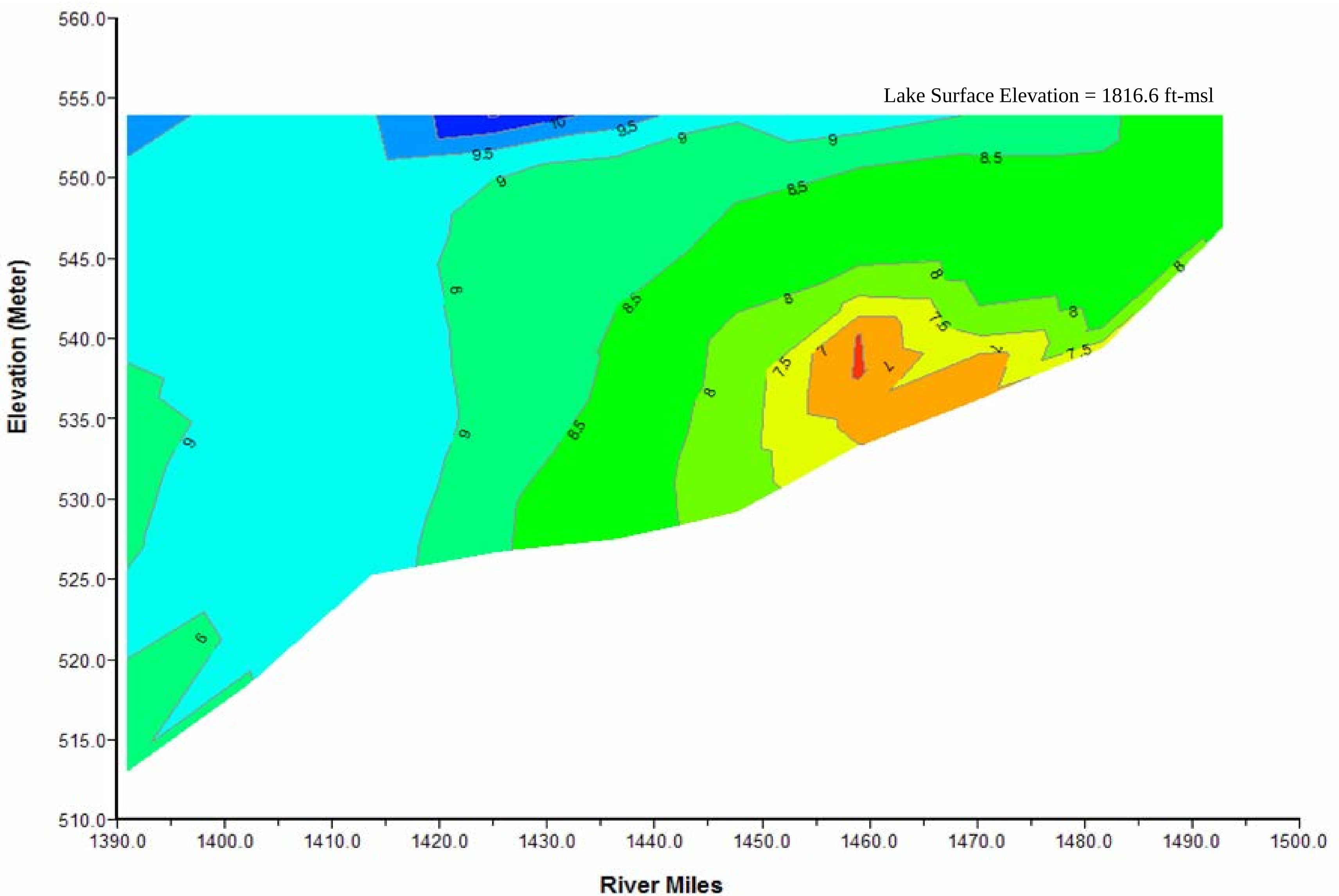

Plate 17. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 24-25, 2004**.**

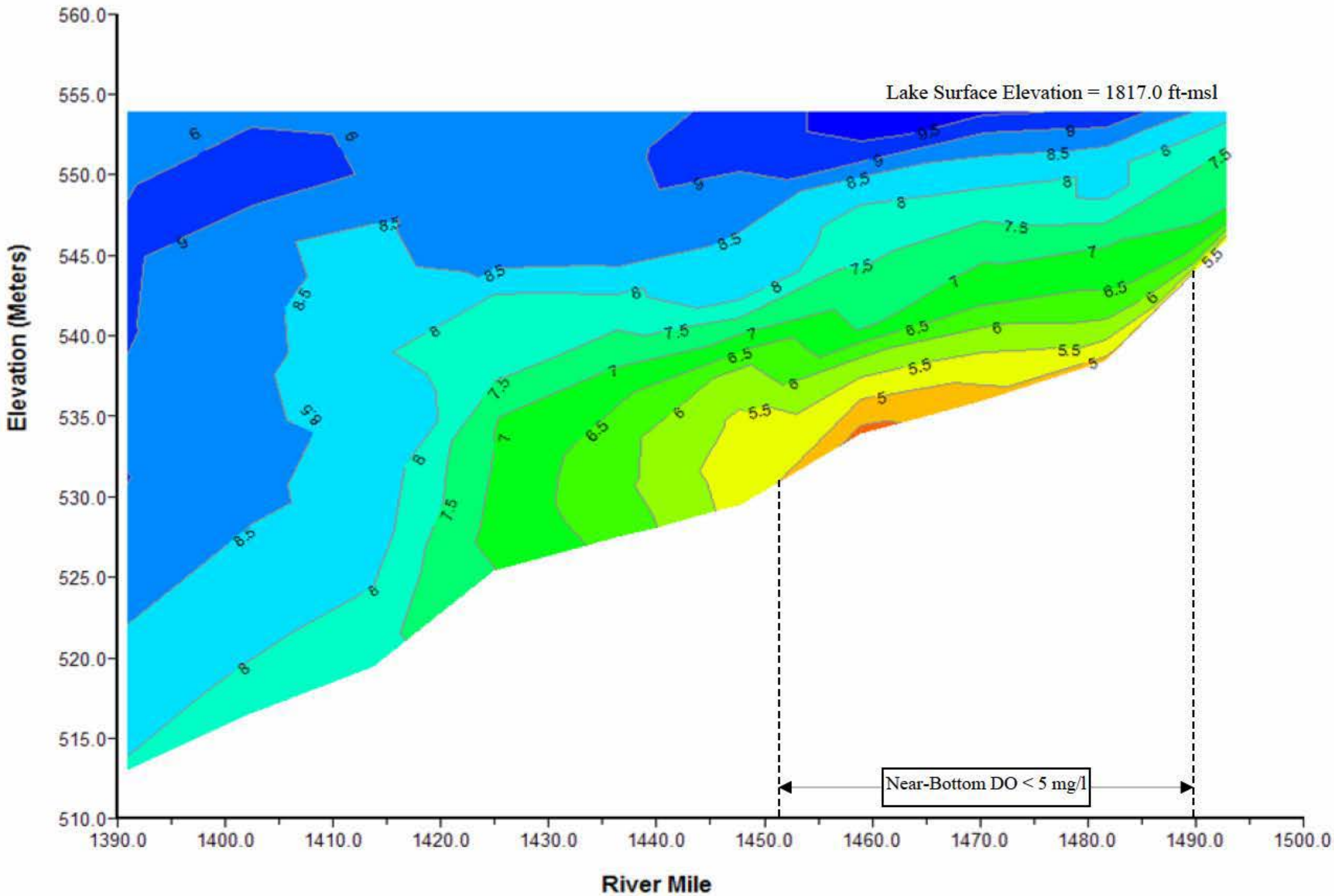

Plate 18. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 19, 2004.

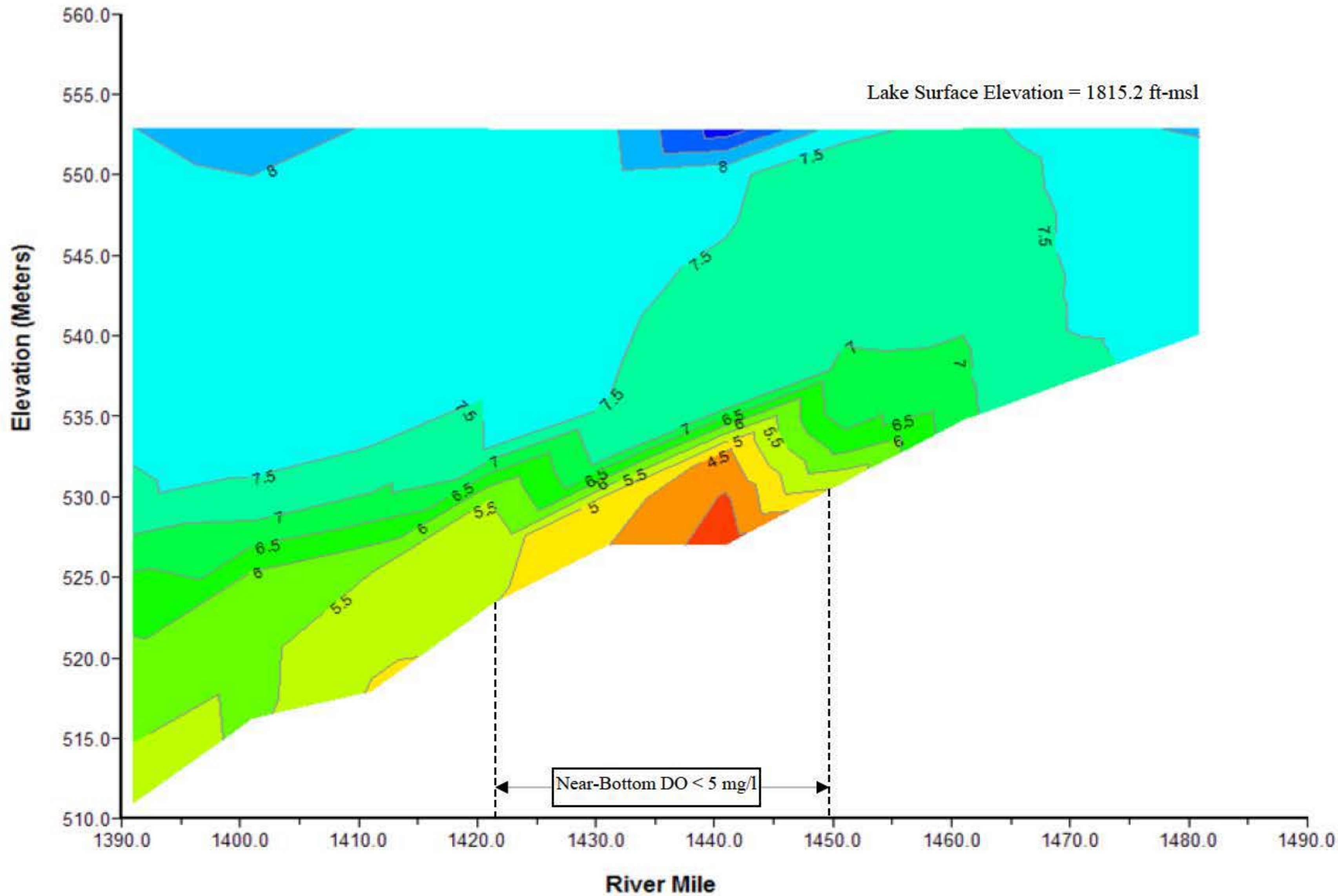

Plate 19. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, and L7 on August 24-25, 2004.

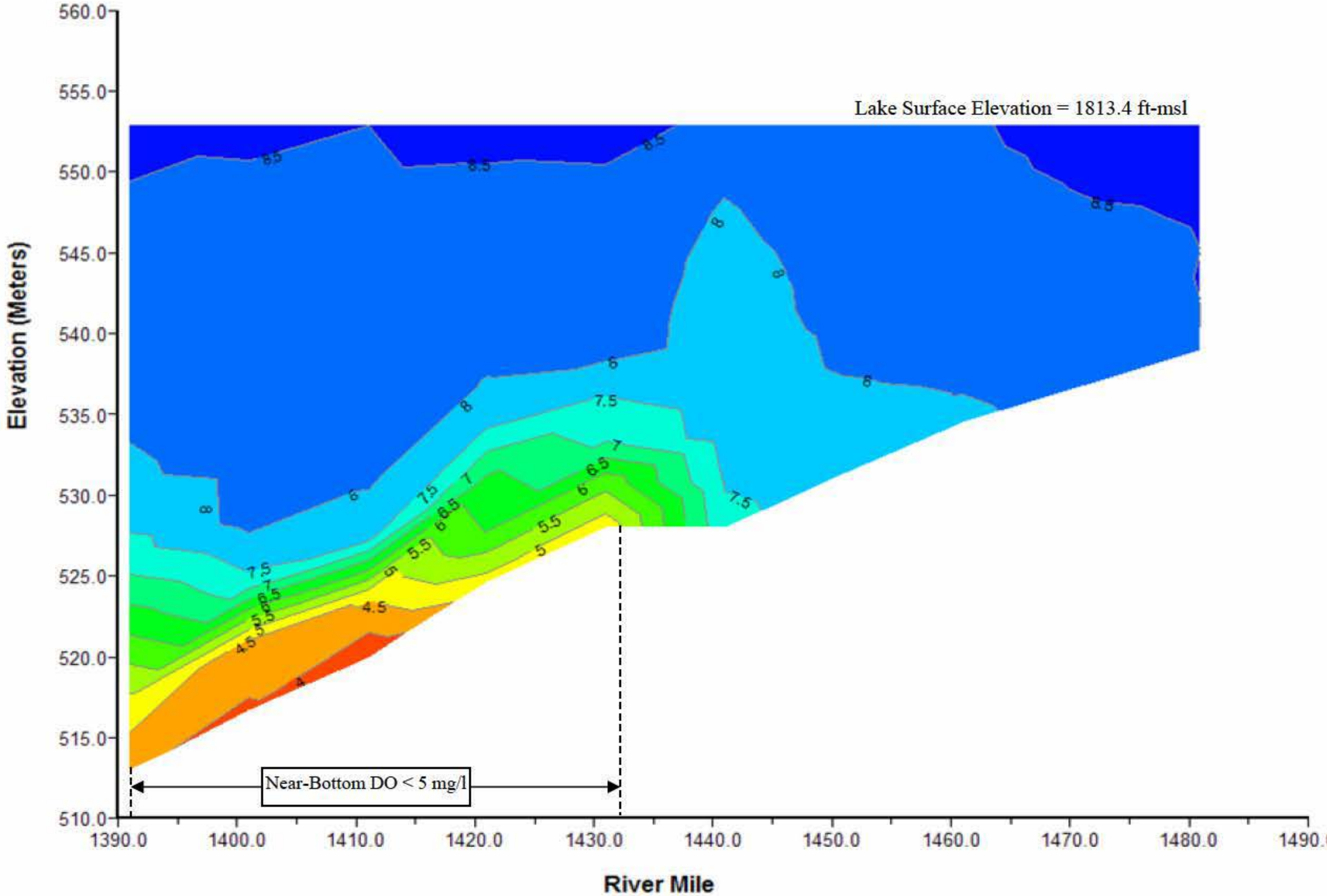

Plate 20. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, and L7 on September 20-21, 2004.

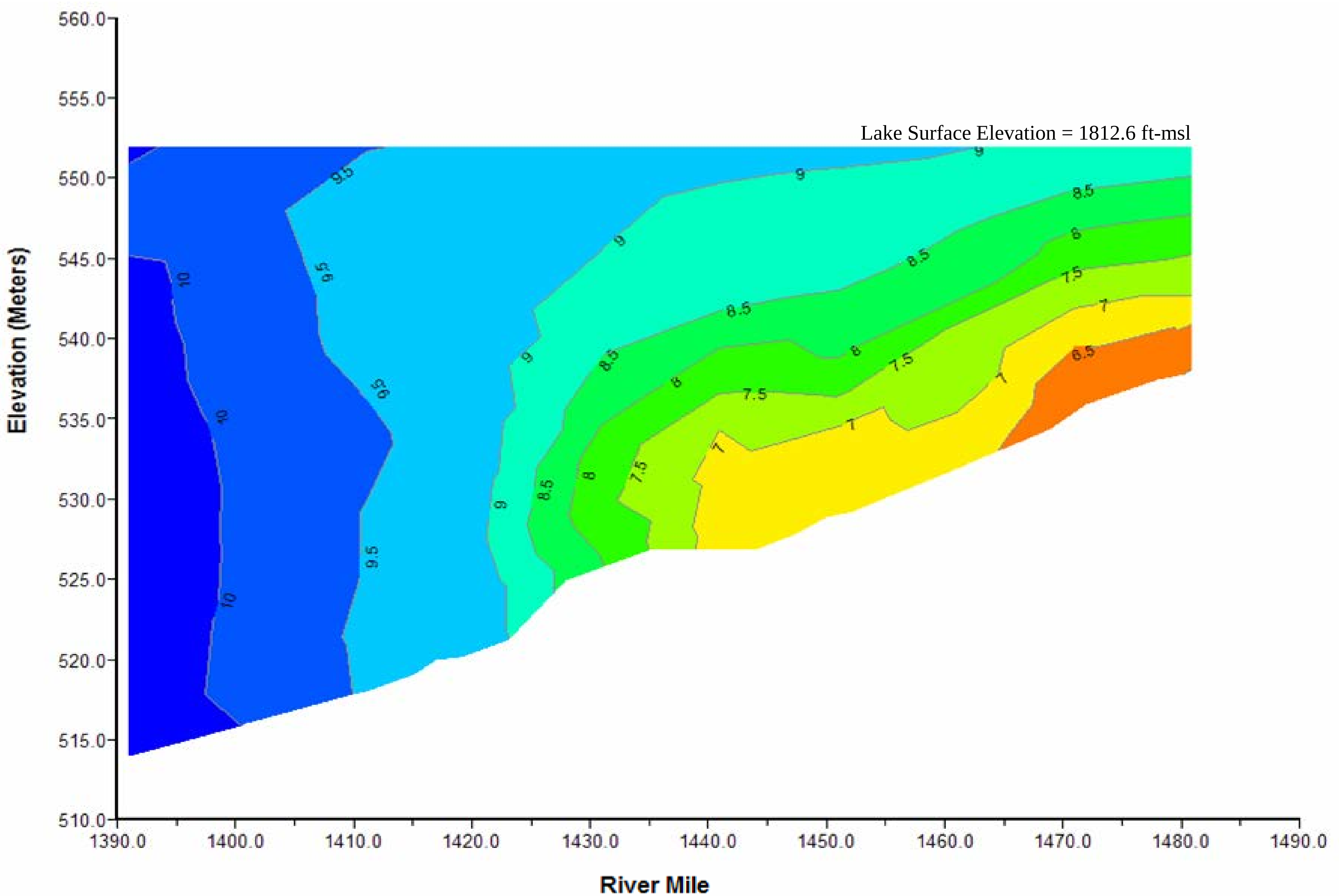

Plate 21. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L3, L5, and L7 on June 21-22, 2005.

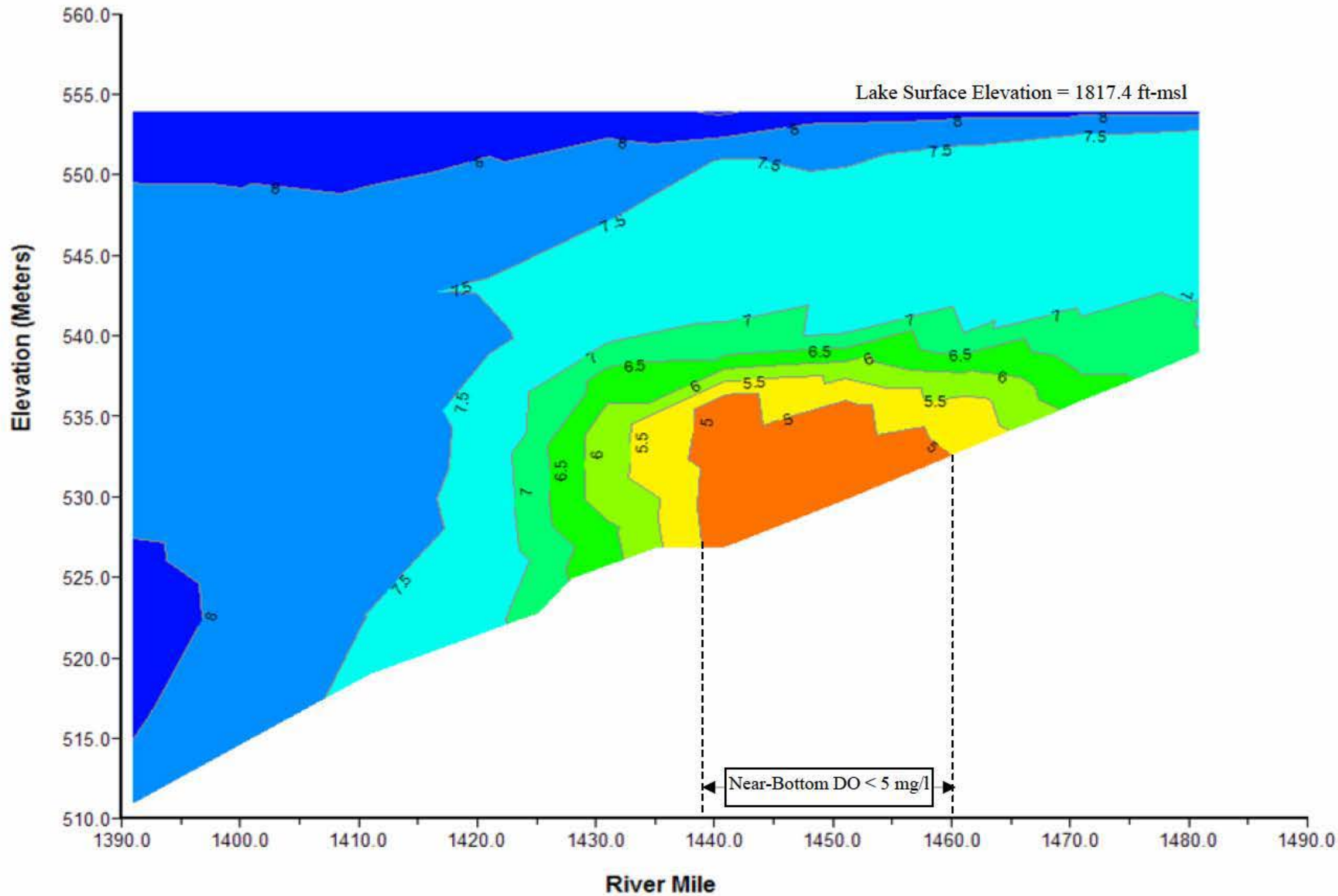

Plate 22. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L3, L5, and L7 on July 19-20, 2005.

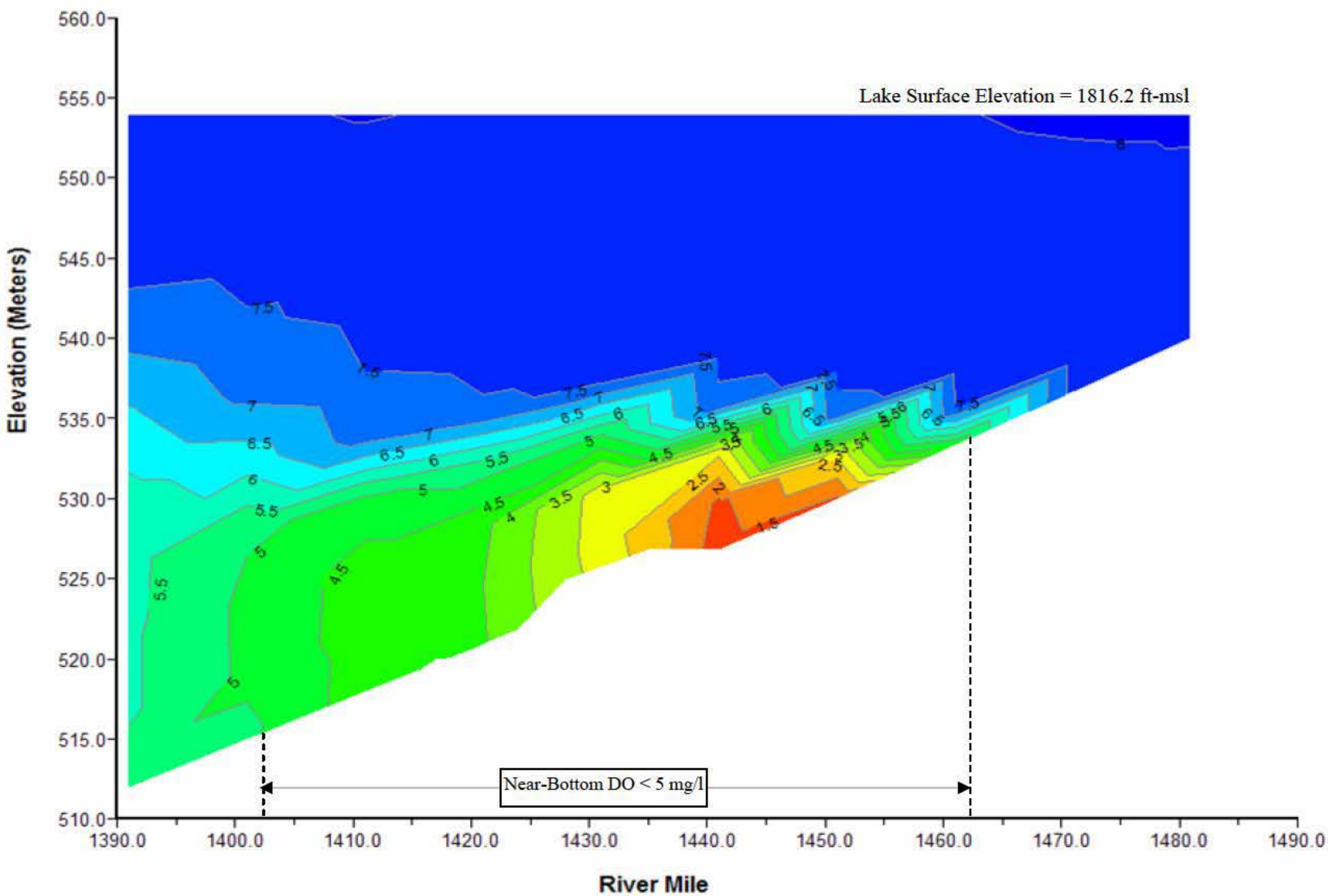

Plate 23. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L3, L5, and L7 on August 23-24, 2005.

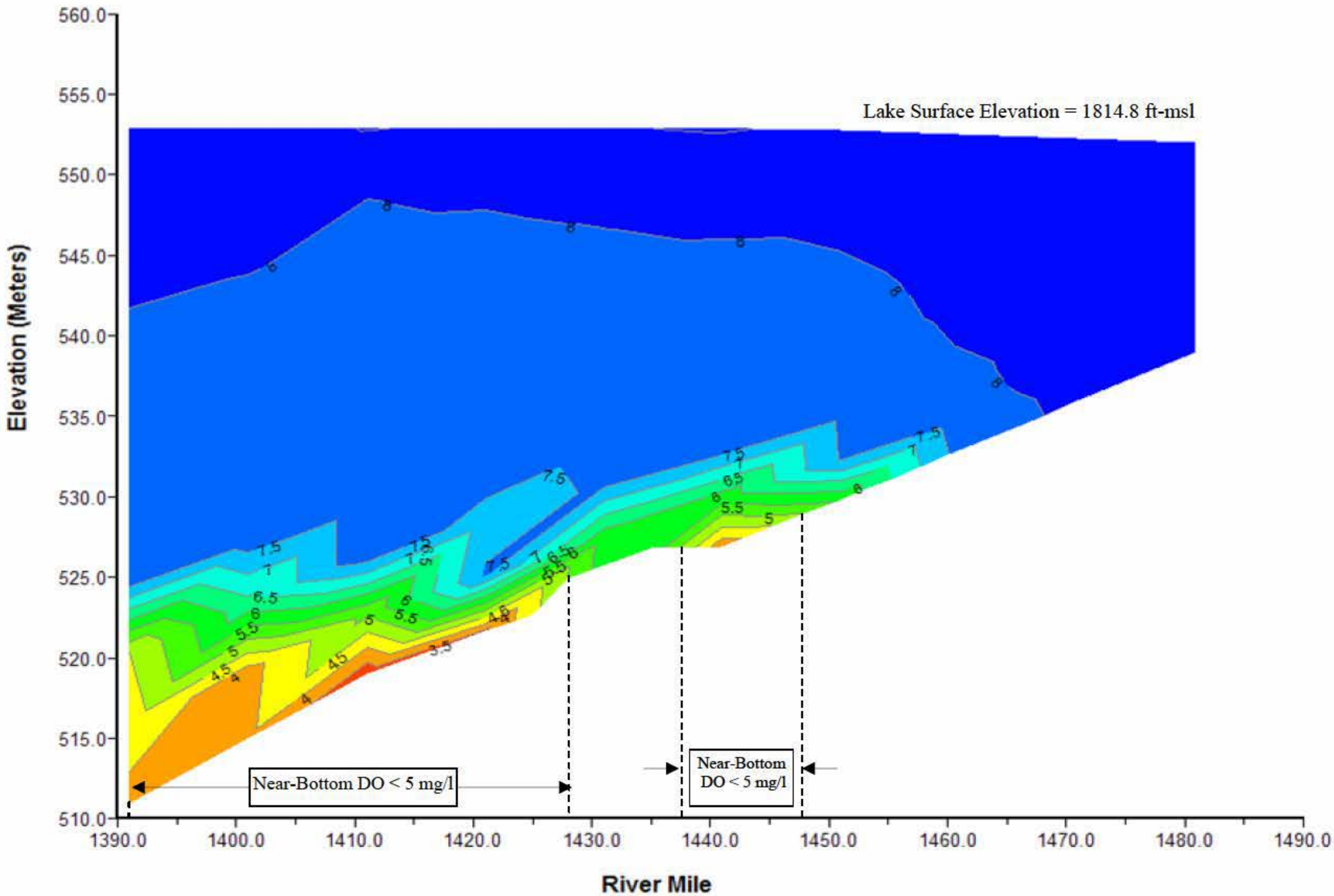

Plate 24. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L3, L5, and L7 on September 19-20, 2005.

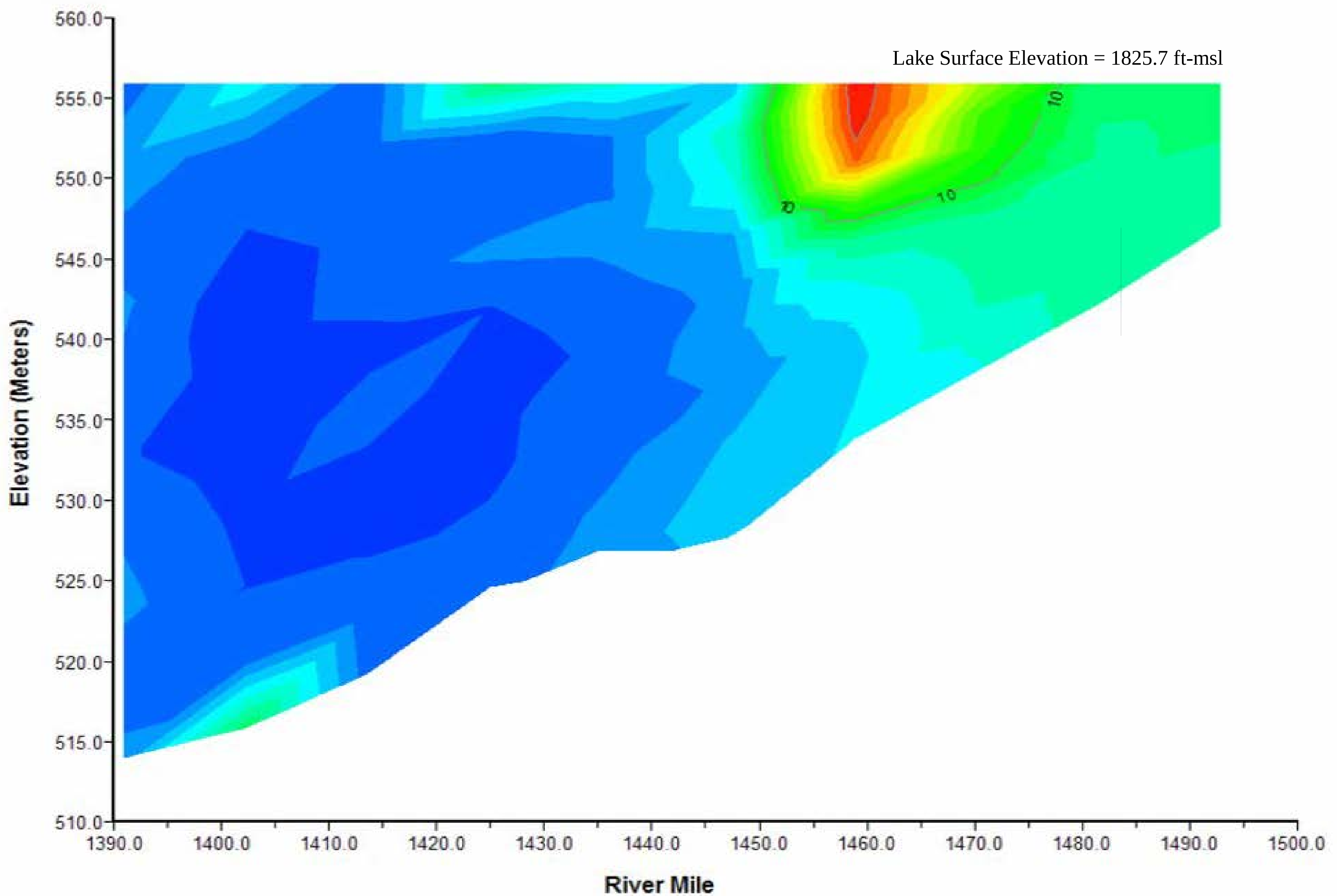

Plate 25. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 17-18, 2003.

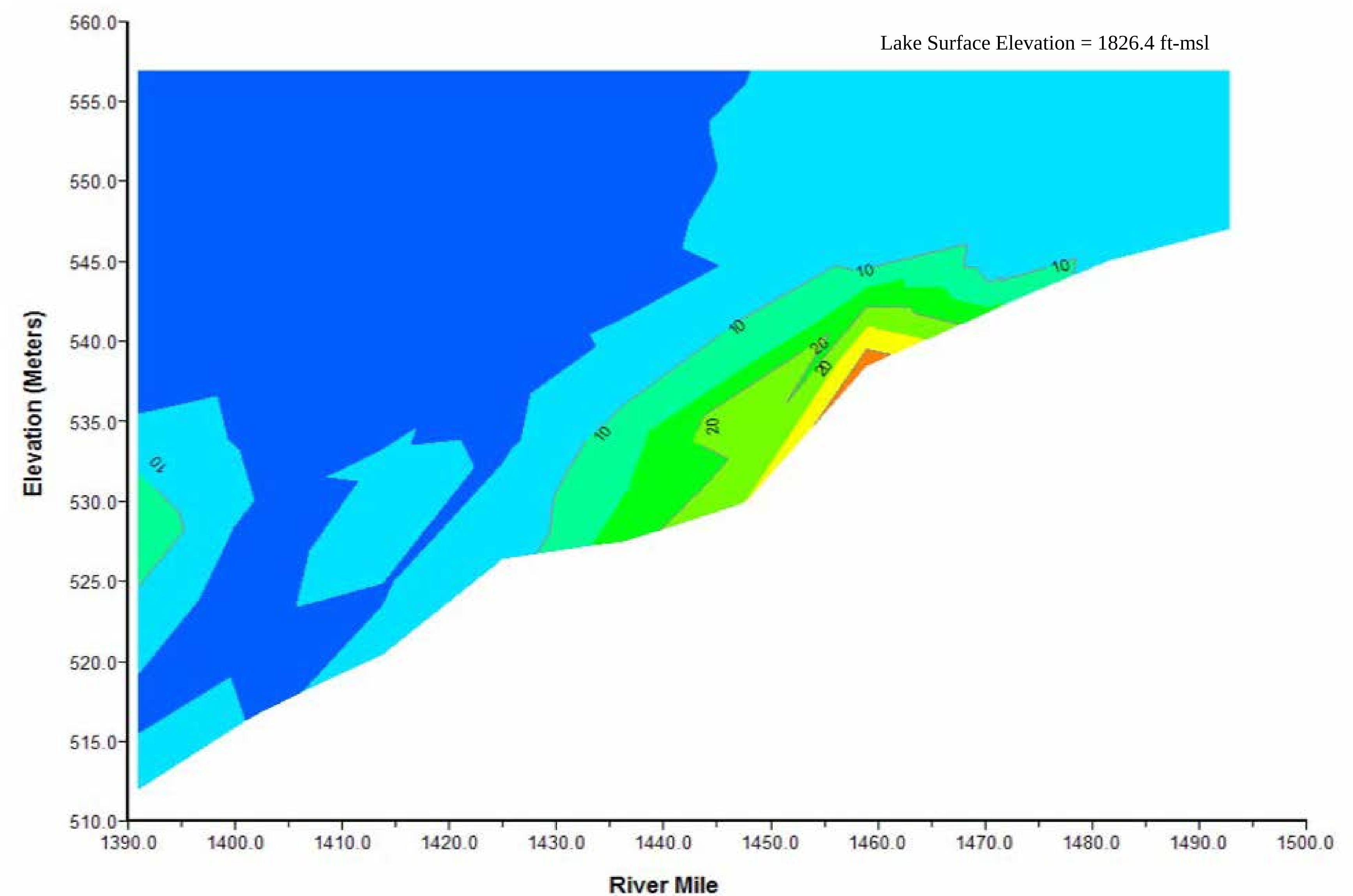

Plate 26. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 29-30, 2003.

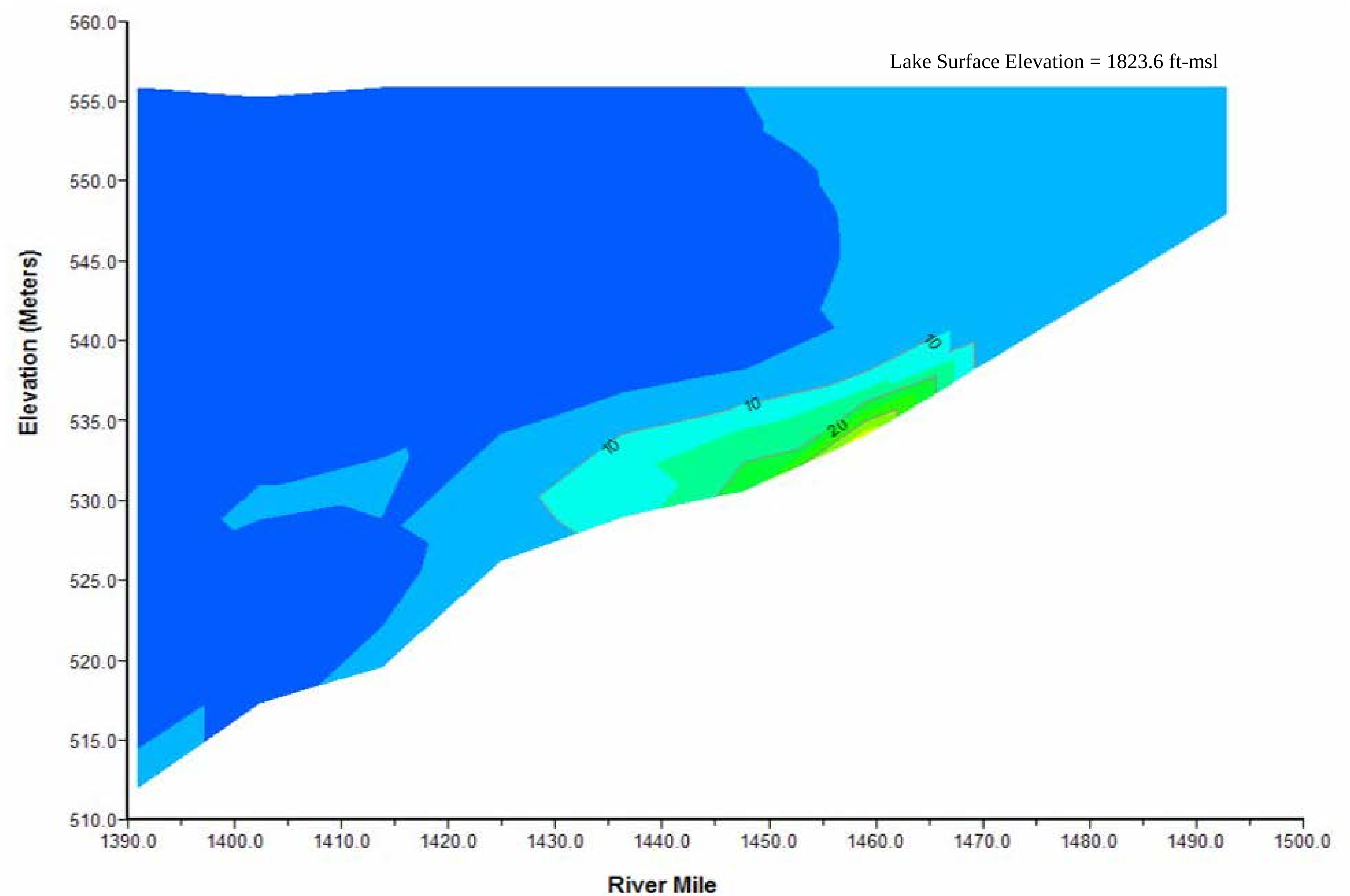

Plate 27. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on August 26-28, 2003**.**

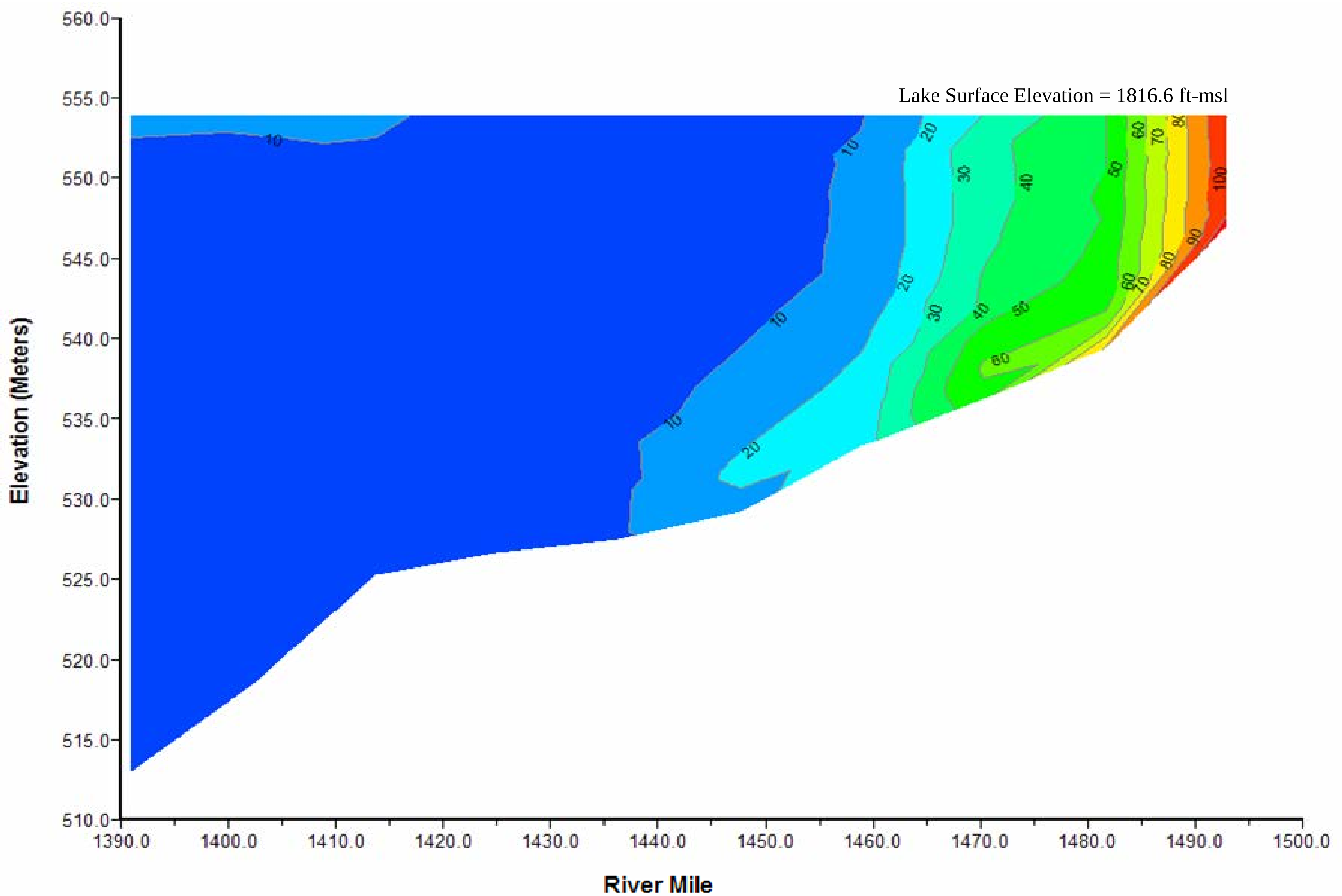

Plate 28. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on June 24-25, 2004.

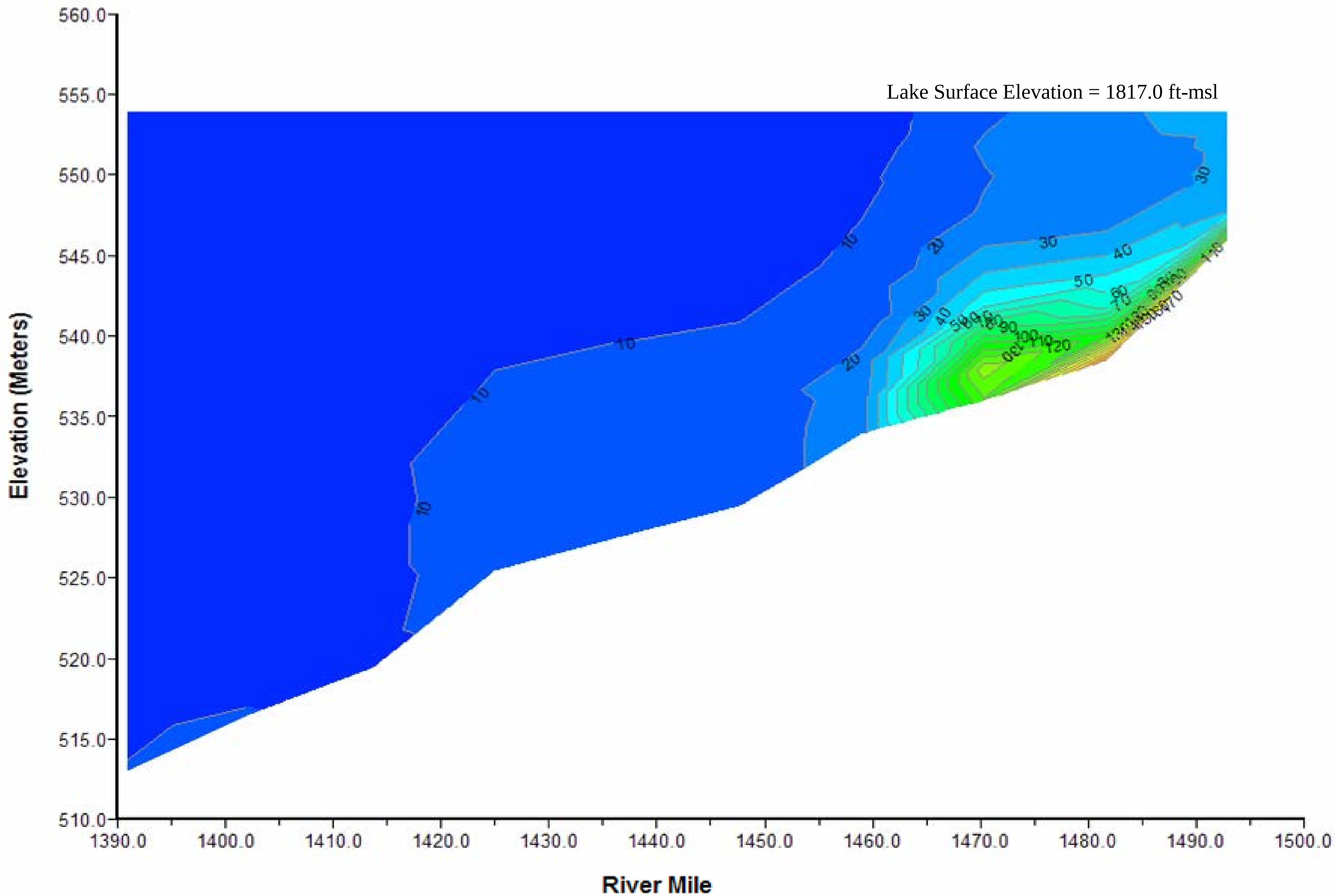

Plate 29. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites L1, L2, L3, L4, L5, L6, L7, and L8 on July 19, 2004.

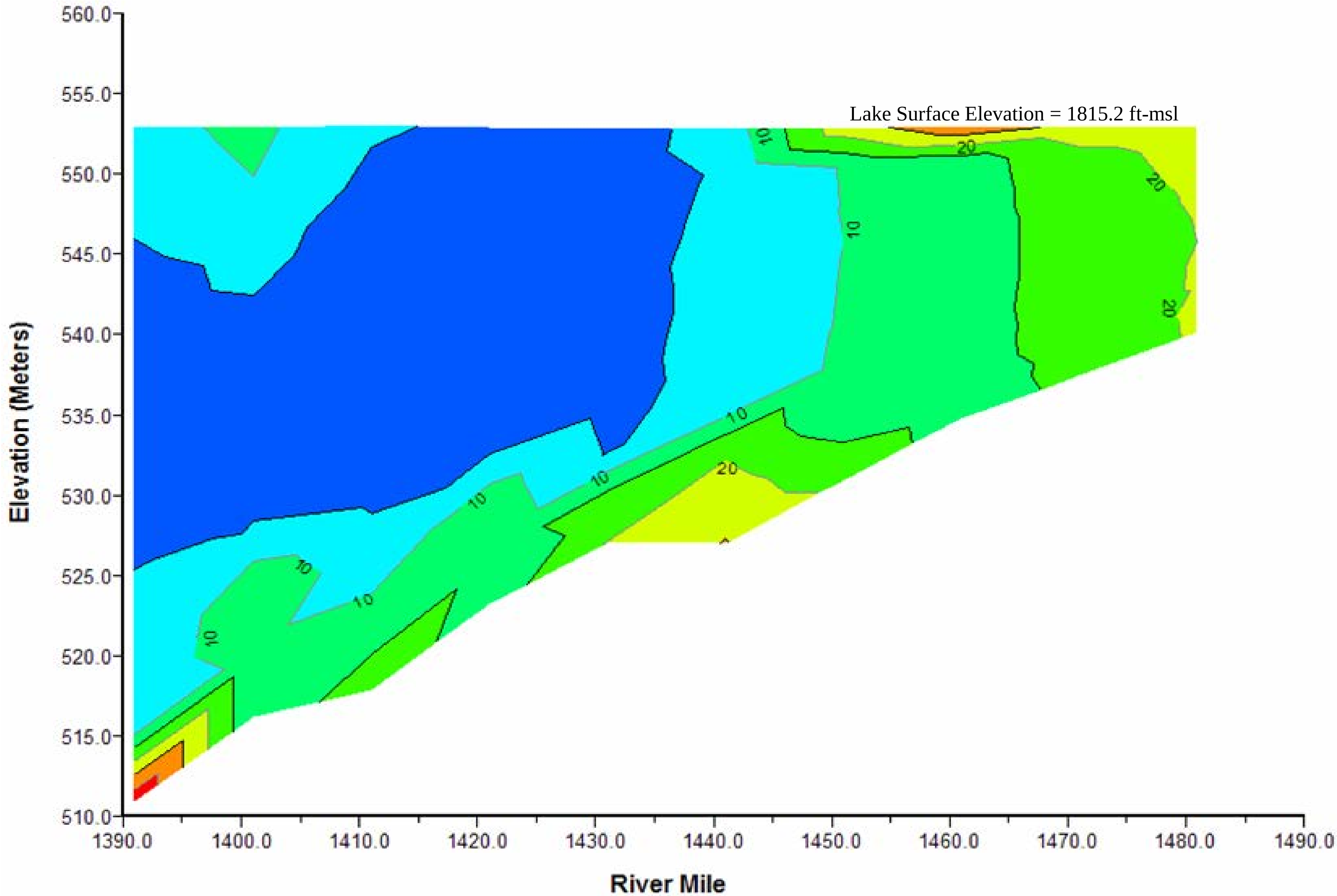

Plate 30. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L2, L3, L4, L5, L6, and L7 on August 24-25, 2004.

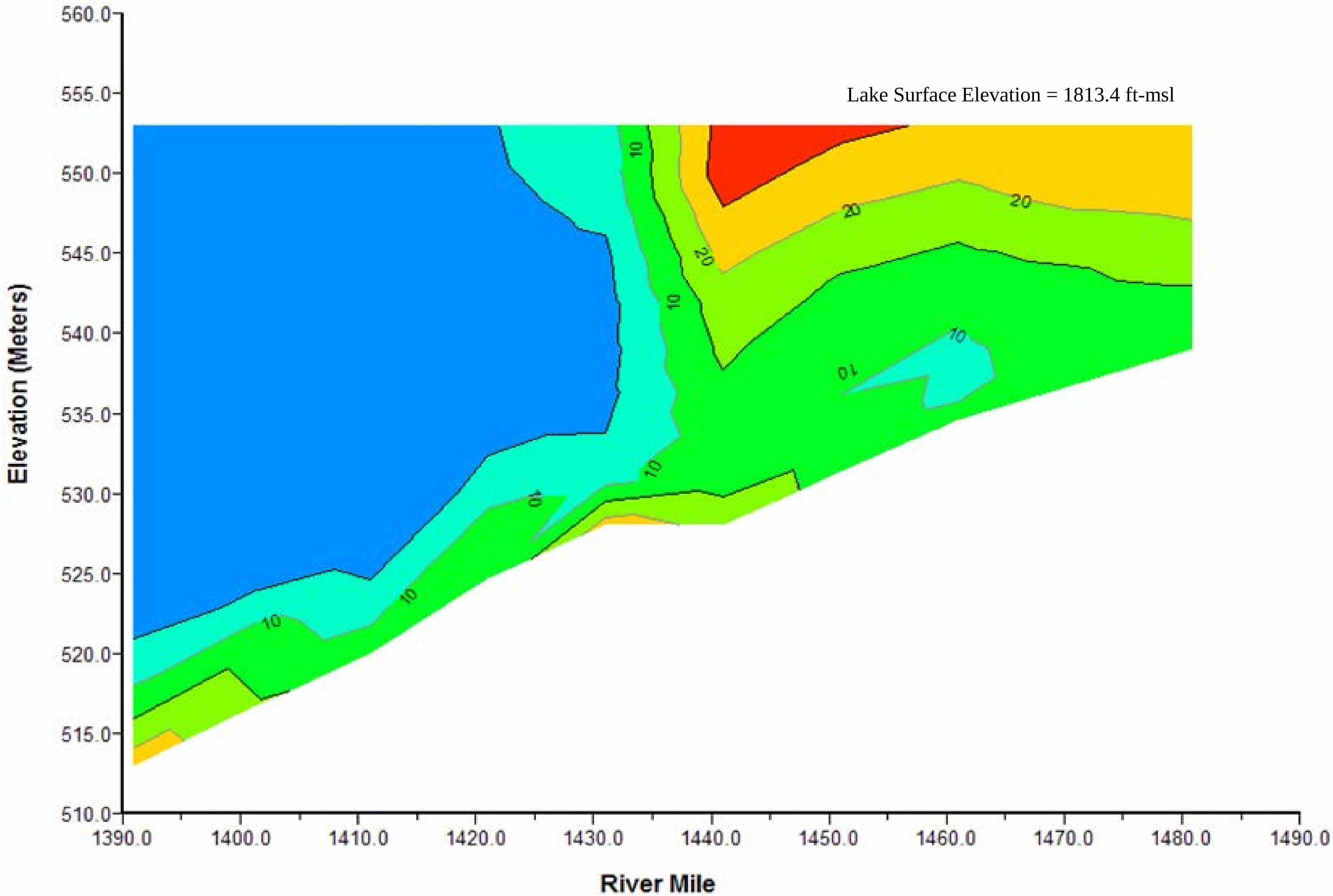

Plate 31. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levelss measured at sites L1, L2, L3, L4, L5, L6, and L7 on September 20-21, 2004.

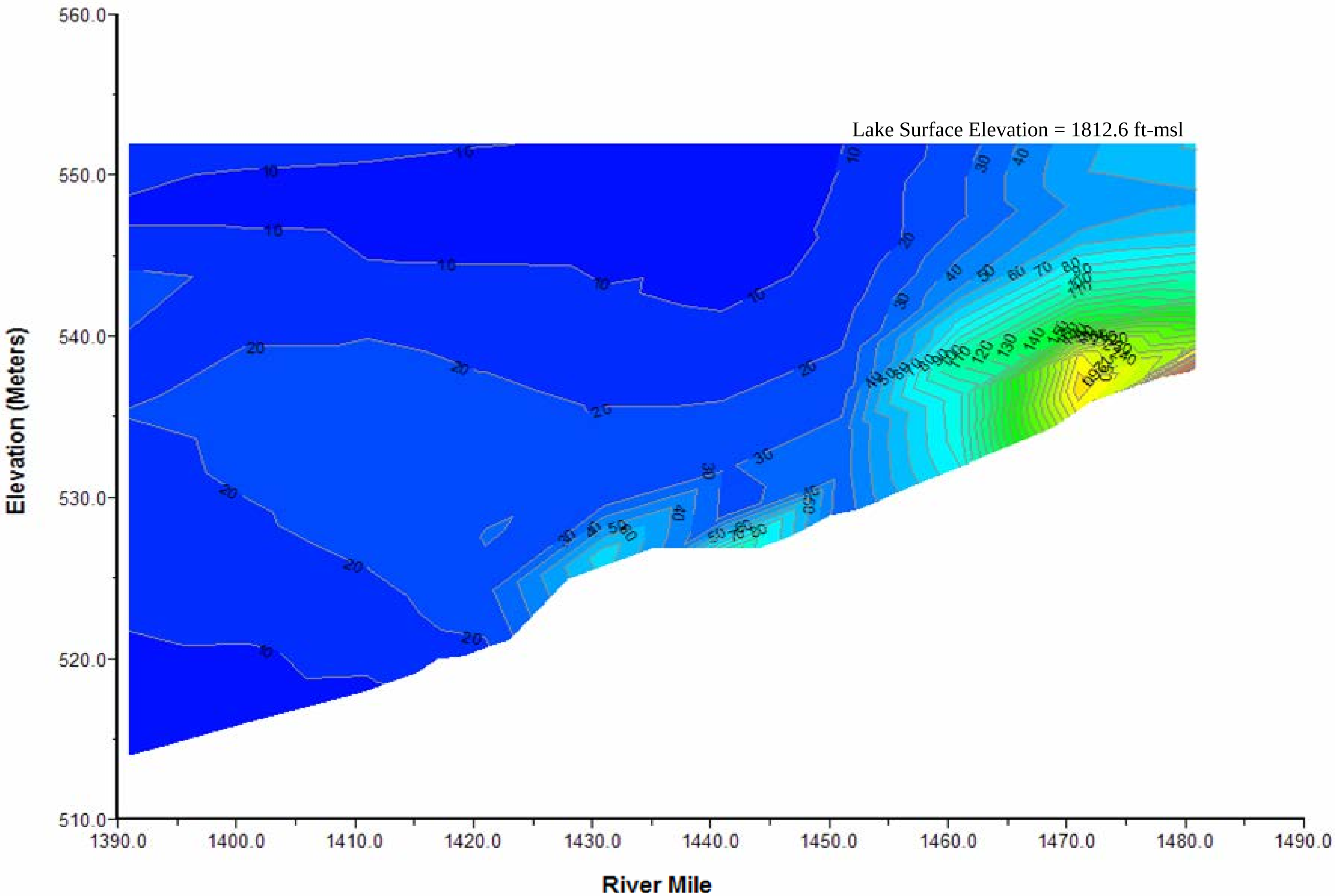

Plate 32. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L3, L5, and L7 on June 21-22, 2005.

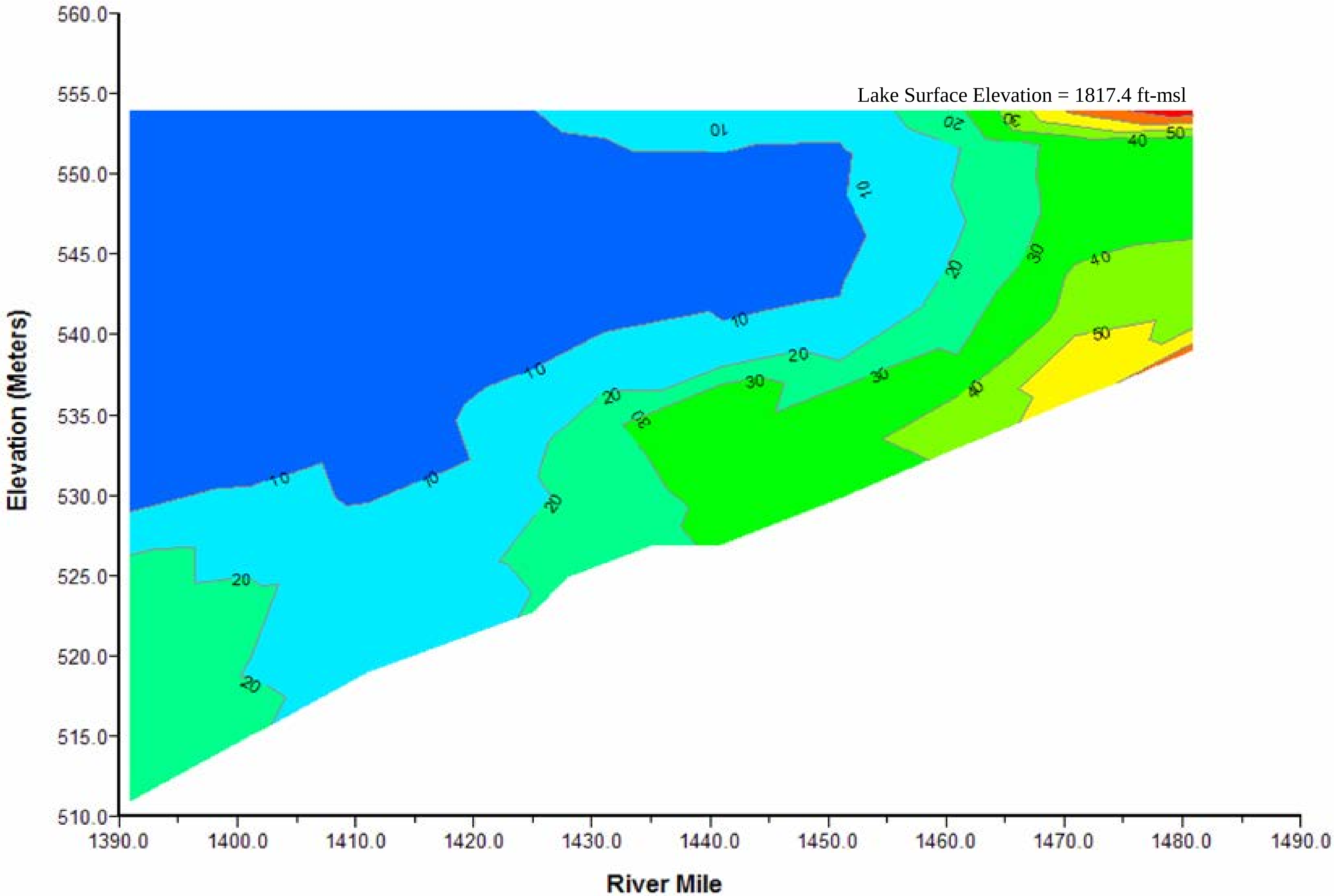

Plate 33. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L3, L5, and L7 on July 19-20, 2005.

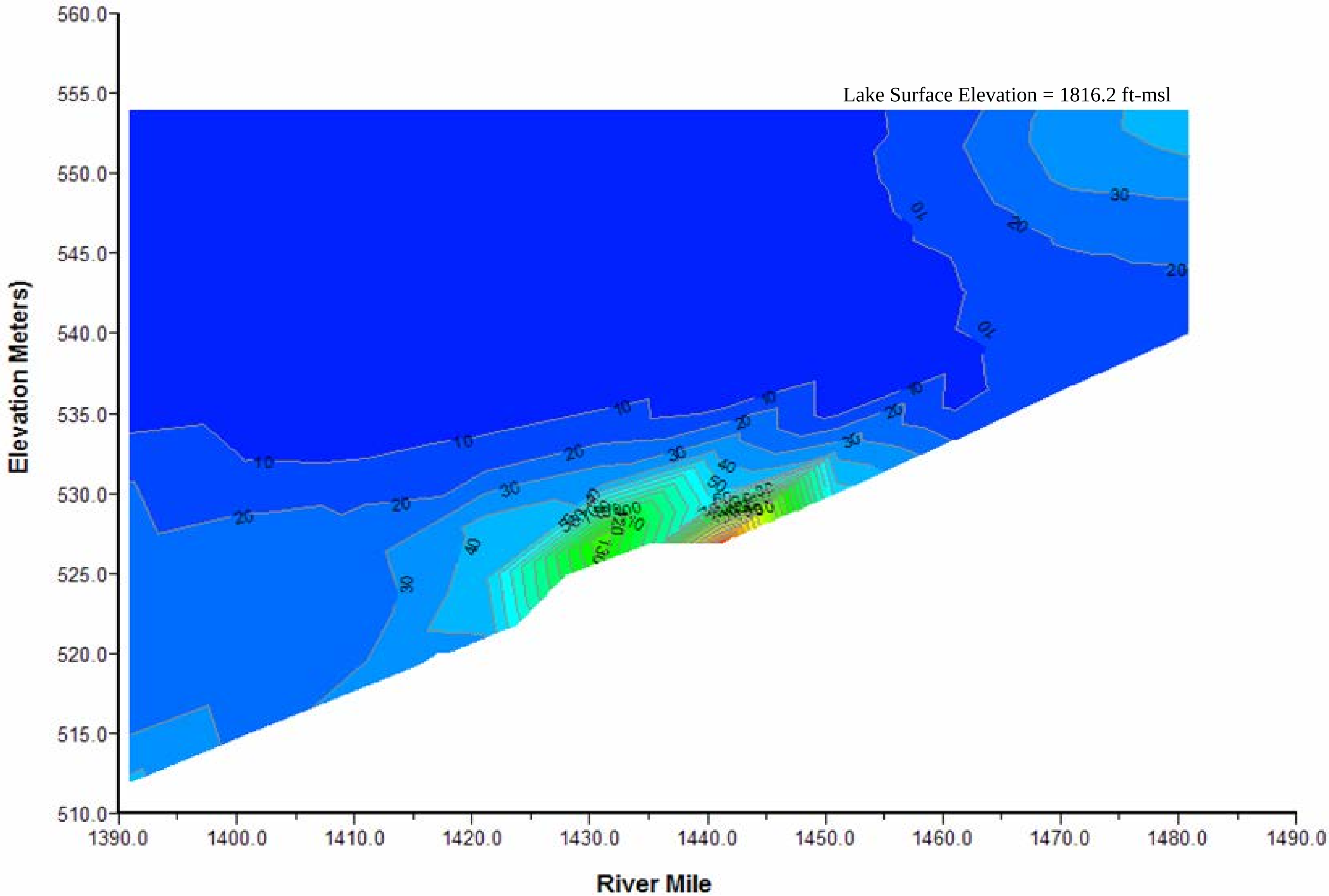

Plate 34. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L3, L5, and L7 on August 23-24, 2005.

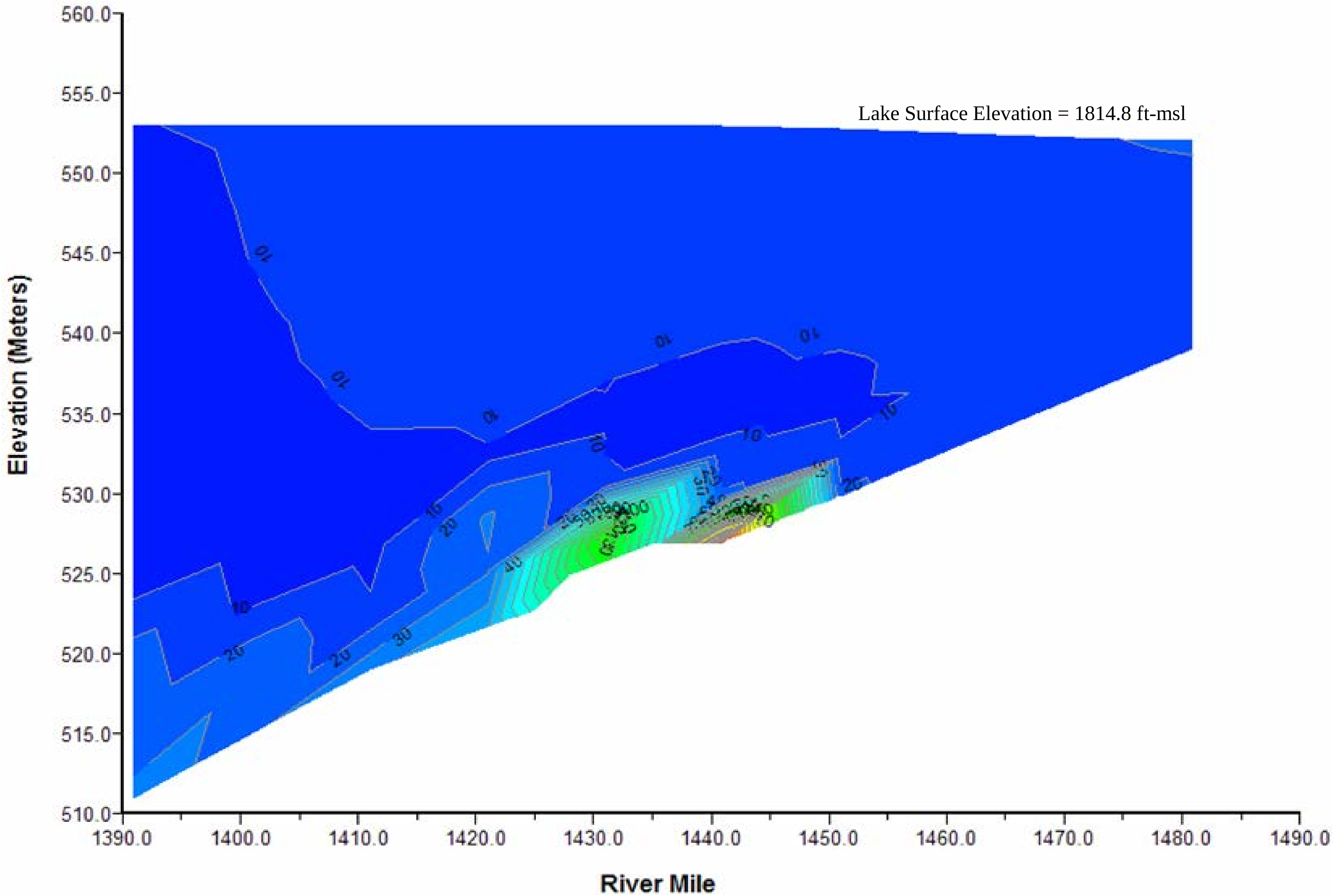

Plate 35. Longitudinal turbidity (NTUs) contour plot of Lake Sakakawea based on depth-profile turbidity levels measured at sites L1, L3, L5, and L7 on September 19-20, 2005.

Plate 36. Phytoplankton total biovolume and percent taxa composition based on biovolume for individual grab samples collected at sites L1, L3, L5, and L7 during the period 2003 through 2005.

Site	Date	Biovolume (um^3)	Bacillariophyta	Chlorophyta	Chrysophyta	Cryptophyta	Cyanobacteria	Pyrrophyta	Euglenophyta
L1	July 2003	122,200,207	21%	26%	-----	44%	2%	7%	-----
L1	Aug 2003	112,361,865	22%	21%	36%	4%	3%	15%	-----
L1	Sep 2003	112,996,588	15%	20%	-----	55%	7%	4%	-----
L1	May 2004	18,358,561	58%	-----	-----	3%	2%	37%	-----
L1	June 2004	1,982,256	53%	-----	-----	35%	12%	-----	-----
L1	July 2004	87,982,899	87%	1%	-----	11%	<1%	-----	-----
L1	Aug 2004	102,328,294	83%	1%	-----	16%	<1%	-----	-----
L1	Sep 2004	207,432,106	84%	2%	-----	13%	<1%	<1%	-----
L1	May 2005	1,366,154,040	99%	<1%	<1%	<1%	-----	-----	-----
L1	June 2005	6,163,686	88%	-----	-----	-----	-----	12%	-----
L1	July 2005	56,944,302	57%	19%	-----	24%	<1%	-----	-----
L1	Aug 2005	103,732,272	42%	11%	-----	29%	<1%	18%	-----
L1	Sep 2005	104,058,345	48%	23%	-----	29%	<1%	-----	-----
L3	July 2003	217,130,630	67%	19%	-----	13%	<1%	-----	-----
L3	Aug 2003	74,760,538	10%	16%	5%	30%	17%	21%	-----
L3	Sep 2003	57,263,603	-----	-----	-----	82%	18%	-----	-----
L3	Jun 2004	1,223,563	-----	-----	-----	41%	42%	17%	-----
L3	July 2004	116,657,513	76%	2%	-----	23%	<1%	-----	-----
L3	Aug 2004	88,140,166	85%	-----	-----	15%	<1%	<1%	-----
L3	Sep 2004	135,965,507	52%	23%	-----	20%	3%	2%	-----
L3	July 2005	233,829,177	42%	15%	<1%	25%	17%	1%	-----
L3	Aug 2005	252,450,665	82%	9%	-----	7%	2%	-----	-----
L3	Sep 2005	76,108,173	38%	11%	-----	36%	14%	<1%	-----

Plate 36. Continued.

Site	Date	Biovolume (um^3)	Bacillariophyta	Chlorophyta	Chrysophyta	Cryptophyta	Cyanobacteria	Pyrrophyta	Euglenophyta
L5	July 2003	98,024,142	35%	15%	5%	14%	29%	<1%	<1%
L5	Aug 2003	572,742,357	87%	<1%	5%	<1%	4%	3%	-----
L5	Sep 2003	204,773,708	65%	3%	-----	14%	18%	<1%	-----
L5	June 2004	1,685,612	62%	-----	-----	21%	17%	-----	-----
L5	July 2004	184,759,537	97%	-----	-----	3%	<1%	-----	-----
L5	Aug 2004	286,075,340	88%	1%	1%	5%	3%	3%	-----
L5	Sep 2004	155,608,125	73%	22%	-----	3%	2%	<1%	<1%
L5	June 2005	117,713,953	66%	21%	-----	11%	1%	<1%	-----
L5	July 2005	72,156,390	46%	<1%	23%	8%	1%	23%	-----
L5	Aug 2005	355,709,437	73%	5%	1%	7%	15%	-----	-----
L5	Sep 2005	177,778,516	8%	36%	-----	4%	50%	3%	-----
L7	Jul 2003	38,391,024	45%	30%	-----	8%	17%	-----	-----
L7	Aug 2003	256,651,533	59%	15%	5%	22%	-----	-----	-----
L7	Sep 2003	404,329,277	49%	1%	-----	21%	29%	-----	-----
L7	June 2004	641,406,981	65%	<1%	-----	34%	<1%	-----	<1%
L7	July 2004	143,415,460	65%	<1%	-----	34%	<1%	-----	<1%
L7	Aug 2004	116,129,651	94%	1%	-----	2%	<1%	3%	-----
L7	Sep 2004	212,404,197	77%	10%	-----	9%	3%	<1%	<1%
L7	June 2005	162,736,063	48%	24%	-----	23%	1%	3%	<1%
L7	July 2005	45,637,096	95%	4%	-----	1%	<1%	-----	-----
L7	Aug 2005	123,071,200	52%	13%	-----	16%	5%	14%	-----
L7	Sep 2005	136,453,162	30%	47%	-----	10%	7%	4%	2%

Plate 37. Listing of phytoplankton taxa collected in Lake Sakakawea at sites L1, L3, L5, and L7 during the period 2003 through 2005.

Division	Genus/Species	Frequency of Occurrence*	Relative Abundance**
Bacillariophyta	Achnanthidium spp.	Rare	Low
Bacillariophyta	Asterionella formossa	Common	High
Bacillariophyta	Aulacoseira granulata	Common	High
Bacillariophyta	Aulacoseira islandica	Common	High
Bacillariophyta	Caloneis limosa	Rare	Very Low
Bacillariophyta	Cocconeis placentula	Occasional	Very Low
Bacillariophyta	Cyclotella spp.	Common	Medium
Bacillariophyta	Cymatopleura solea	Rare	Low
Bacillariophyta	Cymbella spp.	Rare	Low
Bacillariophyta	Diatoma vulgare	Rare	Very Low
Bacillariophyta	Epithemia spp.	Rare	Very Low
Bacillariophyta	Eunotia spp.	Rare	Low
Bacillariophyta	Fragilaria capucina	Rare	Very Low
Bacillariophyta	Fragilaria crotonensis	Common	High
Bacillariophyta	Gomphonema minuta	Rare	Very Low
Bacillariophyta	Gyrosigma spp.	Rare	Very Low
Bacillariophyta	Melosira varians	Rare	Medium
Bacillariophyta	Navicula spp.	Occasional	Very Low
Bacillariophyta	Nitzschia spp.	Occasional	Very Low
Bacillariophyta	Rhoicosphenia curvata	Rare	Medium
Bacillariophyta	Stephanodiscus spp.	Rare	Low
Bacillariophyta	Surirella ovata	Rare	Very Low
Bacillariophyta	Synedra spp.	Common	Low
Bacillariophyta	Tabellaria spp.	Occasional	Low
Chlorophyta	Actinastrum hantzschii	Rare	Very Low
Chlorophyta	Ankistrodesmus falcatus	Rare	Very Low
Chlorophyta	Ankistrodesmus mirabilis	Rare	Very Low
Chlorophyta	Chlamydomonas spp.	Common	High
Chlorophyta	Closteriopsis spp.	Rare	Very Low
Chlorophyta	Closterium spp.	Occasional	Very Low
Chlorophyta	Coelastrum microsporum	Rare	Low
Chlorophyta	Cosmarium spp.	Occasional	Low
Chlorophyta	Crucigenia apiculata	Rare	Low
Chlorophyta	Crucigenia crucifera	Rare	Very Low
Chlorophyta	Crucigenia quadrata	Rare	Very Low
Chlorophyta	Dictyosphaerium pulchellum	Occasional	Very Low
Chlorophyta	Elakatothrix gelatinosa	Rare	Very Low
Chlorophyta	Micractinium spp.	Rare	Very Low
Chlorophyta	Monoraphidium capricornutum	Rare	Very Low
Chlorophyta	Pandorina morum	Occasional	Low
Chlorophyta	Pediastrum biradiatum	Rare	Very Low
Chlorophyta	Pediastrum duplex	Occasional	Low
Chlorophyta	Pediastrum simplex	Rare	Very Low

Plate 37. Continued.

Division	Genus/Species	Frequency of Occurrence*	Relative Abundance**
Chlorophyta	Pleurotaenium spp.	Rare	Medium
Chlorophyta	Quadrigula lacustris	Rare	Very Low
Chlorophyta	Scenedesmus acuminatus	Rare	Low
Chlorophyta	Scenedesmus bijuga	Rare	Very Low
Chlorophyta	Scenedesmus quadricauda	Occasional	Very Low
Chlorophyta	Scenedesmus spp.	Rare	Very Low
Chlorophyta	Selenastrum gracile	Rare	Very Low
Chlorophyta	Selenastrum minutum	Rare	Very Low
Chlorophyta	Sphaerocystis schroeteri	Rare	Medium
Chlorophyta	Spirogyra spp.	Rare	Very Low
Chlorophyta	Staurastrum spp.	Occasional	Low
Chlorophyta	Tetraedon limnetica	Rare	Very Low
Chlorophyta	Tetraedon spp.	Common	Very Low
Chlorophyta	Tetrastrum spp.	Rare	Very Low
Chlorophyta	Ulothrix spp.	Rare	Very Low
Chrysophyta	Dinobryon bavaricum	Rare	Low
Chrysophyta	Dinobryon sertularia	Occasional	High
Chrysophyta	Dinobryon sociale	Rare	Low
Chrysophyta	Mallomonas spp.	Occasional	Low
Chrysophyta	Synura spp.	Rare	Very Low
Cryptophyta	Cryptomonas spp.	Common	Medium
Cryptophyta	Rhodomonas lacustris	Occasional	High
Cryptophyta	Rhodomonas minuta	Common	High
Cyanobacteria	Anabaena circinalis	Common	Very Low
Cyanobacteria	Anabaena spp.	Common	Medium
Cyanobacteria	Anabaenopsis spp.	Occasional	Very Low
Cyanobacteria	Aphanizomenon spp.	Occasional	High
Cyanobacteria	Aphanocapsa spp.	Common	Low
Cyanobacteria	Aphanothece spp.	Common	Very Low
Cyanobacteria	Chroococcus limneticus	Occasional	Very Low
Cyanobacteria	Chroococcus minutus	Common	Very Low
Cyanobacteria	Coelosphaerium kuetzingianum	Occasional	Low
Cyanobacteria	Cylindrospermopsis spp.	Occasional	High
Cyanobacteria	Dactylococcopsis irregula	Rare	Very Low
Cyanobacteria	Gomphosphaeria lacustris	Rare	Low
Cyanobacteria	Lyngbya limnetica	Rare	Very Low
Cyanobacteria	Merismopedia elegans	Rare	Very Low
Cyanobacteria	Merismopedia glauca	Rare	Very Low
Cyanobacteria	Merismopedia tenuissima	Occasional	Very Low
Cyanobacteria	Microcystis aeruginosa	Occasional	Very Low
Cyanobacteria	Microcystis flos-aquae	Occasional	Very Low
Cyanobacteria	Oscillatoria spp.	Occasional	Medium
Cyanobacteria	Pseudanabaena spp.	Common	Very Low

Plate 37. Continued.

Division	Genus/Species	Frequency of Occurrence*	Relative Abundance**
Cyanobacteria	Raphidiopsis curvata	Rare	Low
Cyanobacteria	Synechococcus spp.	Rare	Very Low
Euglenophyta	Eulgena acus	Rare	Low
Euglenophyta	Phacus spp.	Rare	Very Low
Euglenophyta	Trachelomonas spp.	Rare	Low
Pyrrophyta	Ceratium hirundinella	Common	Medium
Pyrrophyta	Glenodinium spp.	Rare	Low
Pyrrophyta	Peridinium spp.	Common	Low

* Frequency of occurrence based on the number of samples where the taxa were present:
Present in 1 to 4 samples = Rare.
Present in 5 to 10 samples = Occasional.
Present in 11 or more samples = Common.
Note: A total of 45 phytoplankton samples were collected.

** Relative abundance based on the percent biovolume of the individual taxa of the total sample biovolume:
Taxa biovolume <1% of total sample biolvolume = Very Low.
Taxa biovolume 1 to 5% of total sample biolvolume = Low.
Taxa biovolume 5 to 10% of total sample biolvolume = Medium.
Taxa biovolume >10% of total sample biolvolume = High.

Plate 38. Estimate of coldwater habitats present in Lake Sakakawea on June 17, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	1.6	7.1	5	3.8	
Elevation (ft-msl) of 18.3°C Water	1825.7	1825.7	1825.7	1825.7	1820.5	1802.4	1809.3	1813.2	
Volume (ac-ft) of Water ≤ 18.3°C	1,459,859	2,783,473	2,500,286	2,008,429	1,616,975	943,235	924,948	521,900	12,759,105
Depth (meters) of 15°C Water	4.3	6.8	9.2	9.4	6.7	9.5	10.8	Bottom	
Elevation (msl) of 15°C Water	1811.7	1803.5	1795.6	1795	1803.8	1794.6	1790.4	Bottom	
Volume (ac-ft) of Water ≤ 15°C	1,199,450	2,107,161	1,614,285	1,271,282	1,159,821	730,764	477,916	0	8,560,679
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	260,409	676,312	886,001	737,147	457,154	212,471	447,032	521,900	4,198,426
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0	0
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1811.7 to Bottom	1803.5 to Bottom	1795.6 to Bottom	1795.0 to Bottom	1803.8 to Bottom	1794.6 to Bottom	1790.4 to Bottom	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1,199,450	2,107,161	1,614,285	1,271,282	1,159,821	730,764	477,916	0	8,560,679
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1825.7 to 1811.7	1825.7 to 1803.5	1825.7 to 1795.6	1825.7 to 1795.0	1820.5 to 1803.8	1802.4 to 1794.6	1809.3 to 1790.4	1813.2 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	260,409	676,312	886,001	737,147	457,154	212,471	447,032	521,900	4,198,426
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,459,859	2,783,473	2,500,286	2,008,429	1,616,975	943,235	924,948	521,900	12,759,105

Note: Lake elevation on June 17, 2003 = 1,825.7 feet-msl. Approximate lake volume on June 17, 2003 = 14,808,125 acre-feet.

Plate 39. Estimate of coldwater habitats present in Lake Sakakawea on July 1, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	2.3	Surface	6	1	8.3	Bottom	
Elevation (ft-msl) of 18.3°C Water	1827	1827	1819.5	1827	1807.3	1823.7	1799.8	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	1,485,678	2,825,288	2,305,802	2,041,925	1,249,948	1,752,922	692,079	0	12,353,642
Depth (meters) of 15°C Water	22	19	14	12	12.5	10	10.5	Bottom	
Elevation (msl) of 15°C Water	1754.8	1764.7	1781.1	1787.7	1786	1794.2	1792.6	Bottom	
Volume (ac-ft) of Water ≤ 15°C	448,797	1,103,830	1,235,968	1,111,395	751,306	720,844	527,078	0	5,899,218
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,036,881	1,721,458	1,069,834	930,530	498,642	1,032,078	165,001	0	6,454,424
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0	0
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1754.8 to Bottom	1764.7 to Bottom	1781.1 to Bottom	1787.7 to Bottom	1786.0 to Bottom	1794.2 to Bottom	1792.6 to Bottom	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	448,797	1,103,830	1,235,968	1,111,395	751,306	720,844	527,078	0	5,899,218
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1827.0 to 1754.8	1827.0 to 1764.7	1819.5 to 1781.1	1827.0 to 1787.7	1807.3 to 1786.0	1823.7 to 1794.2	1799.8 to 1792.6	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,036,881	1,721,458	1,069,834	930,530	498,642	1,032,078	165,001	0	6,454,424
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,485,678	2,825,288	2,305,802	2,041,925	1,249,948	1,752,922	692,079	0	12,353,642

Note: Lake elevation on July 1, 2003 = 1,827.0 feet-msl. Approximate lake volume on July 1, 2003 = 15,152,547 acre-feet.

Plate 40. Estimate of coldwater habitats present in Lake Sakakawea on July 16, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	14.4	13.3	13.5	7.6	10.5	9	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1779.8	1783.4	1782.7	1802.1	1792.5	1797.5	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	725,906	1,559,976	1,276,647	1,431,506	890,690	803,015	0	0	6,687,740
Depth (meters) of 15°C Water	18	22.5	21.5	18	16	12.5	Bottom	Bottom	
Elevation (msl) of 15°C Water	1768	1753.2	1756.5	1768	1774.5	1786	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	587,487	848,437	692,262	706,947	527,801	538,887	0	0	3,901,821
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	138,419	711,539	584,385	724,559	362,889	264,128	0	0	2,785,919
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0	0
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1768.0 to Bottom	1753.2 to Bottom	1756.5 to Bottom	1768.0 to Bottom	1774.5 to Bottom	1786.0 to Bottom	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	587,487	848,437	692,262	706,947	527,801	538,887	0	0	3,901,821
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1779.8 to 1768.0	1783.4 to 1753.2	1782.7 to 1756.5	1802.1 to 1768.0	1792.5 to 1774.5	1797.5 to 1786.0	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	138,419	711,539	584,385	724,559	362,889	264,128	0	0	2,785,919
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	725,906	1,559,976	1,276,647	1,431,506	890,690	803,015	0	0	6,687,740

Note: Lake elevation on July 16, 2003 = 1,827.0 feet-msl. Approximate lake volume on July 16, 2003 = 15,152,547 acre-feet.

Plate 41. Estimate of coldwater habitats present in Lake Sakakawea on July 30, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	21.9	19.9	18.7	14	10.3	12.9	10.8	Bottom	
Elevation (ft-msl) of 18.3°C Water	1754.5	1761.1	1765	1780.5	1792.6	1784.1	1791	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	445,830	1,020,480	866,566	958,853	892,973	502,051	491,323	0	5,178,076
Depth (meters) of 15°C Water	23.5	23.5	22.5	17.6	16.2	14.3	Bottom	Bottom	
Elevation (msl) of 15°C Water	1749.3	1749.3	1752.6	1768.7	1773.2	1779.5	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	394,977	765,703	616,987	720,555	504,148	414,905	0	0	3,417,275
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	50,853	254,777	249,579	238,298	388,825	87,146	491,323	0	1,760,801
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	15.4	11.5	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	1775.9	1788.7	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	357,701	442,179	0	799,880
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1749.3 to Bottom	1749.3 to Bottom	1752.6 to Bottom	1768.7 to Bottom	1773.2 to Bottom	1779.5 to 1775.9	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	394,977	765,703	616,987	720,555	504,148	57,204	0	0	3,059,574
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1754.5 to 1749.3	1761.1 to 1749.3	1765.0 to 1752.6	1780.5 to 1768.7	1792.6 to 1773.2	1784.1 to 1779.5	1791.0 to 1788.7	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	50,853	254,777	249,579	238,298	388,825	87,146	49,144	0	1,318,622
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	445,830	1,020,480	866,566	958,853	892,973	144,350	49,144	0	4,378,196

Note: Lake elevation on July 30, 2003 = 1,826.4 feet-msl. Approximate lake volume on July 30, 2003 = 14,993,583 acre-feet.

Plate 42. Estimate of coldwater habitats present in Lake Sakakawea on August 12, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Region 6**	**Region 7**	**Region 8**	**Total (acre-ft)**
Depth (meters) of 18.3°C Water	13.5	14.3	15.3	19.4	21.1	21.3	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1780.7	1778.1	1774.8	1761.3	1755.8	1755.1	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	737,519	1,425,199	1,085,966	576,965	231,197	94,886	0	0	4,151,732
Depth (meters) of 15°C Water	21.1	19.9	21.9	21.6	25.5	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1755.7	1759.7	1753.1	1754.1	1741.3	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	457,707	988,544	626,638	441,142	65,777	0	0	0	2,579,808
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	279,812	436,655	459,328	135,823	165,420	94,886	0	0	1,571,924
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	20.8	21.3	21.3	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1756.8	1755.1	1755.1	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	491,741	221,668	94,886	0	0	808,295
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1755.7 to Bottom	1759.7 to Bottom	1753.1 to Bottom	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	457,707	988,544	626,638	0	0	0	0	0	2,072,889
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1780.7 to 1755.7	1778.1 to 1759.7	1774.8 to 1753.1	1761.3 to 1756.8	1755.8 to 1755.1	0	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	279,812	436,655	459,328	85,224	9,529	0	0	0	1,270,548
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	737,519	1,425,199	1,085,966	85,224	9,529	0	0	0	3,343,437

Note: Lake elevation on August 12, 2003 = 1,825.0 feet-msl. Approximate lake volume on August 12, 2003 = 14,622,667 acre-feet.

Plate 43. Estimate of coldwater habitats present in Lake Sakakawea on August 28, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	20.6	20.3	20.3	20	20.3	Bottom	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1756.0	1757.0	1757.0	1758.0	1757.0	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	460,678	930,336	701,912	514,258	247,531	0	0	0	2,854,715
Depth (meters) of 15°C Water	26.5	23.8	23.3	22.2	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1736.6	1745.5	1747.2	1750.8	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	286,257	690,855	518,341	379,459	0	0	0	0	1,874,912
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	174,421	239,481	183,571	134,799	247,531	0	0	0	979,803
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	21	19.8	19.4	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1754.7	1758.6	1762.6	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	452,357	269,311	170,883	0	0	892,551
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1736.6 to Bottom	1745.5 to Bottom	1747.2 to Bottom	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	286,257	690,855	518,341	0	0	0	0	0	1,495,453
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1756.0 to 1736.6	1757.0 to 1745.5	1757.0 to 1747.2	1758.0 to 1754.7	0	0	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	174,421	239,481	183,571	61,901	0	0	0	0	659,374
Volume (acre-ft) of Total Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	460,678	930,336	701,912	61,901	0	0	0	0	2,154,827

Note: Lake elevation on August 28, 2003 = 1,823.6 feet-msl. Approximate lake volume on August 28, 2003 = 14,254,081 acre-feet.

Plate 44. Estimate of coldwater habitats present in Lake Sakakawea on September 9, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	23	24	22.7	23	22	21.5	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1746.6	1743.4	1747.6	1746.6	1749.9	1751.6	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	370,500	649,513	525,264	304,611	151,252	64,410	0	0	2,065,550
Depth (meters) of 15°C Water	27.4	26.6	24.9	24.8	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1732.2	1734.8	1740.4	1740.7	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	247,741	490,106	400,645	200,988	0	0	0	0	1,339,480
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	122,759	159,407	124,619	103,623	151,252	64,410	0	0	726,070
Depth of 5 mg/l DO Water	Bottom	29	26.4	23.4	22.1	19.6	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	1727	1735.5	1745.3	1749.6	1757.8	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	357,973	322,104	281,710	148,270	118,743	0	0	1,228,800
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1732.2 to Bottom	1734.8 to 1727.0	1740.4 to 1735.5	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	247,740	132,133	78,541	0	0	0	0	0	458,414
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1746.6 to 1732.2	1743.4 to 1734.8	1747.6 to 1740.4	1746.6 to 1745.3	1749.9 to 1749.6	0	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	122,759	159,407	124,619	22,901	2,982	0	0	0	432,668
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	370,499	291,540	203,160	22,901	2,982	0	0	0	891,082

Note: Lake elevation on September 9, 2003 = 1,822.1 feet-msl. Approximate lake volume on September 9, 2003 = 13,859,168 acre-feet.

Plate 45. Estimate of coldwater habitats present in Lake Sakakawea on September 23, 2003 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	-----*	-----*	-----*	-----*	
Elevation (ft-msl) of 18.3°C Water	1821.4	1821.4	1821.4	1821.4	1821.4	1821.4	1821.4	1821.4	
Volume (ac-ft) of Water ≤ 18.3°C	1,374,503	2,645,208	2,364,902	1,897,893	1,645,678	1,648,692	1,245,705	852,296	13,674,877
Depth (meters) of 15°C Water	37.4	32.3	30.9	27.8	-----*	-----*	-----*	-----*	
Elevation (msl) of 15°C Water	1698.7	1715.4	1720	1730.2	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	36,990	190,036	94,771	63,780	0	0	0	0	385,577
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,337,513	2,455,172	2,270,131	1,834,113	1,645,678	1,648,692	1,245,705	852,296	13,289,300
Depth of 5 mg/l DO Water	38.8	35.6	32.5	Bottom	-----*	-----*	-----*	-----*	
Elevation of 5 mg/l DO Water	1694.1	1704.6	1714.8	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	23,417	74,897	54,097	0	0	0	0	0	152,411
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1698.7 to 1694.1	1715.4 to 1704.6	1720.0 to 1714.8	1730.2 to Bottom	0**	0**	0**	0**	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	13,573	115,139	40,674	63,780	0	0	0	0	233,166
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1821.4 to 1698.7	1821.4 to 1715.4	1821.4 to 1720.0	1821.4 to 1730.2	1821.4 to Bottom***	1821.4 to Bottom***	1821.4 to Bottom***	1821.4 to Bottom***	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,337,513	2,455,172	2,270,131	1,834,113	1,645,678	1,648,692	1,245,705	852,296	13,289,300
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,351,086	2,570,311	2,310,805	1,897,893	1,645,678	1,648,692	1,245,705	852,296	13,522,466

* Sites L5, L6, L7, and L8 were not sampled due to equipment problems.

** Assumed to be 0 based on conditions at L1, L2, L3, and L4 (i.e., water assumed to be "isothermal" at about 16.5°C and dissolved oxygen > 5.0 mg/l).

*** Assumed to be surface to bottom based on conditions at L1, L2, L3, L4, and NF1 (i.e., water assumed to be "isothermal" at about 16.5°C and dissolved oxygen > 5.0 mg/l; water temperature of the Missouri River at NF1 was measured at 11.5°C).

Note: Lake elevation on September 23, 2003 = 1,821.4 feet-msl. Approximate lake volume on September 23, 2003 = 13,674,876 acre-feet.

Plate 46. Estimate of coldwater habitats present in Lake Sakakawea on June 24, 2004 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1816.6	1816.6	1816.6	1816.6	1816.6	1816.6	1816.6	1816.6	
Volume (ac-ft) of Water ≤ 18.3°C	1,286,373	2,496,561	2,218,674	1,778,008	1,505,155	1,450,825	1,115,240	652,457	12,503,293
Depth (meters) of 15°C Water	Surface	Surface	Surface	Surface	Surface	11.2	Bottom	Bottom	
Elevation (msl) of 15°C Water	1816.6	1816.6	1816.6	1816.6	1816.6	1779.9	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	1,286,373	2,496,561	2,218,674	1,778,008	1,505,155	421,261	0	0	9,706,032
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	0	0	0	0	0	1,029,564	1,115,240	652,457	2,797,261
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0	0
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1816.6 to Bottom	1816.6 to Bottom	1816.6 to Bottom	1816.6 to Bottom	1816.6 to Bottom	1779.9 to Bottom	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1,286,373	2,496,561	2,218,674	1,778,008	1,505,155	421,261	0	0	9,706,032
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	0	0	0	0	0	1816.6 to 1779.9	1816.6 to Bottom	1816.6 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	0	0	0	0	0	1,029,564	1,115,240	652,457	2,797,261
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,286,373	2,496,561	2,218,674	1,778,008	1,505,155	1,450,825	1,115,240	652,457	12,503,293

Note: Lake elevation on June 24, 2004 = 1,816.6 feet-msl. Approximate lake volume on June 24, 2004 = 12,503,293 acre-feet.

Plate 47. Estimate of coldwater habitats present in Lake Sakakawea on July 19, 2004 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	7.2	6	6.7	10.8	12.1	12.2	11.7	Bottom	
Elevation (ft-msl) of 18.3°C Water	1793.4	1797.3	1795	1781.6	1777.3	1777	1778.6	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	910,126	1,931,647	1,597,995	982,128	578,745	375,180	246,522	0	6,622,343
Depth (meters) of 15°C Water	15.3	13.8	16.5	15.5	14.5	15.9	Bottom	Bottom	
Elevation (msl) of 15°C Water	1766.8	1771.7	1762.9	1766.2	1769.4	1764.8	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	574,398	1,268,277	821,731	671,954	436,472	198,552	0	0	3,971,384
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	335,728	663,370	776,264	310,174	142,273	176,628	246,522	0	2,650,959
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	18	15.3	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	1758	1766.8	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	120,511	94,455	0	214,966
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1766.8 to Bottom	1771.7 to Bottom	1762.9 to Bottom	1766.2 to Bottom	1769.4 to Bottom	1764.8 to 1758.0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	574,398	1,268,277	821,731	671,954	436,472	78,041	0	0	3,850,873
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1793.4 to 1766.8	1797.3 to 1771.7	1795.0 to 1762.9	1781.6 to 1766.2	1777.3 to 1769.4	1777.0 to 1764.8	1778.6 to 1766.8	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	335,728	663,370	776,264	310,174	142,273	176,628	152,067	0	2,556,504
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	910,126	1,931,647	1,597,995	982,128	578,745	254,669	152,067	0	6,407,377

Note: Lake elevation on July 19, 2004 = 1,817.0 feet-msl. Approximate lake volume on July 19, 2004 = 12,597,763 acre-feet.

Plate 48. Estimate of coldwater habitats present in Lake Sakakawea on August 24, 2004 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Region 6**	**Region 7**	**Region 8**	**Total (acre-ft)**
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1815.2	1815.2	1815.2	1815.2	1815.2	1815.2	1815.2	1815.2	
Volume (ac-ft) of Water ≤ 18.3°C	1,261,527	2,453,889	2,176,612	1,743,456	1,465,678	1,395,474	1,077,680	598,332	12,172,648
Depth (meters) of 15°C Water	29.2	25.2	25.2	22.7	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1719.4	1732.5	1732.5	1740.7	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	154,104	449,230	274,358	200,988	0	0	0	0	1,078,680
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,107,423	2,004,659	1,902,254	1,542,468	1,465,678	1,395,474	1,077,680	598,332	11,093,968
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	22.9	18	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1740.1	1756.1	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	190,461	235,280	0	0	0	425,741
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1719.4 to Bottom	1732.5 to Bottom	1732.5 to Bottom	1740.7 to 1740.1	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	154,104	449,230	274,358	10,527	0	0	0	0	888,219
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1815.2 to 1719.4	1815.2 to 1732.5	1815.2 to 1732.5	1815.2 to 1740.1	1815.2 to 1756.1	1815.2 to Bottom	1815.2 to Bottom	1815.2 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,107,423	2,004,659	1,902,254	1,542,468	1,230,398	1,395,474	1,077,680	598,332	10,858,688
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,261,527	2,453,889	2,176,612	1,552,995	1,230,398	1,395,474	1,077,680	598,332	11,746,907

Note: Lake elevation on August 24, 2004 = 1815.2 feet-msl. Approximate lake volume on August 24, 2004 = 12,172,647 acre-feet.

Plate 49. Estimate of coldwater habitats present in Lake Sakakawea on September 8, 2004 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1813.8	1813.8	1813.8	1813.8	1813.8	1813.8	1813.8	1813.8	
Volume (ac-ft) of Water ≤ 18.3°C	1,236,695	2,411,232	2,134,550	1,708,990	1,426,303	1,340,283	1,041,146	544,800	11,843,999
Depth (meters) of 15°C Water	31.6	29.7	27.7	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1710.1	1716.4	1722.9	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	95,314	202,807	135,312	0	0	0	0	0	433,433
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,141,381	2,208,425	1,999,238	1,708,990	1,426,303	1,340,283	1,041,146	544,800	11,410,566
Depth of 5 mg/l DO Water	37.5	33.9	31.3	Bottom	21.2	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	1690.8	1702.6	1711.1	Bottom	1744.2	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	13,701	57,795	25,154	0	94,600	0	0	0	191,250
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1710.1 to 1690.8	1716.4 to 1702.6	1722.9 to 1711.1	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	81,613	145,012	110,158	0	0	0	0	0	336,783
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1813.8 to 1710.1	1813.8 to 1716.4	1813.8 to 1722.9	1813.8 to Bottom	1813.8 to 1744.2	1813.8 to Bottom	1813.8 to Bottom	1813.8 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,141,381	2,208,424	1,999,238	1,708,990	1,331,703	1,340,283	1,041,146	544,800	11,315,965
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,222,994	2,353,436	2,109,396	1,708,990	1,331,703	1,340,283	1,041,146	544,800	11,652,748

Note: Lake elevation on September 8, 2004 = 1813.8 feet-msl. Approximate lake volume on August 24, 2004 = 11,843,999 acre-feet.

Plate 50. Estimate of coldwater habitats present in Lake Sakakawea on September 20, 2004 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1813.4	1813.4	1813.4	1813.4	1813.4	1813.4	1813.4	1813.4	
Volume (ac-ft) of Water ≤ 18.3°C	1,229,600	2,399,045	2,122,532	1,699,147	1,415,058	1,324,521	1,030,757	529,534	11,750,194
Depth (meters) of 15°C Water	31.3	30.3	28.7	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1710.7	1714	1719.2	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	99,103	172,170	88,513	0	0	0	0	0	359,786
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,130,497	2,226,875	2,034,019	1,699,147	1,415,058	1,324,521	1,030,757	529,534	11,390,408
Depth of 5 mg/l DO Water	35.5	31.1	28.6	23.1	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	1696.9	1711.4	1719.6	1737.6	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	31,661	133,126	91,642	158,028	0	0	0	0	414,457
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1710.7 to 1696.9	1714.0 to 1711.4	0	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	67,442	39,044	0	0	0	0	0	0	106,486
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1813.4 to 1710.7	1813.4 to 1714.0	1813.4 to 1719.6	1813.4 to 1737.6	1813.4 to Bottom	1813.4 to Bottom	1813.4 to Bottom	1813.4 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,130,497	2,226,875	2,030,890	1,541,119	1,415,058	1,324,521	1,030,757	529,534	11,229,251
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,197,939	2,265,919	2,030,890	1,541,119	1,415,058	1,324,521	1,030,757	529,534	11,335,737

Note: Lake elevation on September 20, 2004 = 1813.4 feet-msl. Approximate lake volume on August 24, 2004 = 11,750,195 acre-feet.

Plate 51. Estimate of coldwater habitats present in Lake Sakakawea on June 22, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	2.7	5.1	9.1	9.7	11.1	13	Bottom	
Elevation (ft-msl) of 18.3°C Water	1812.6	1803.7	1795.9	1782.7	1780.8	1776.2	1769.9	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	1,215,412	2,112,953	1,622,431	1,005,403	644,328	362,468	123,359	0	7,086,354
Depth (meters) of 15°C Water	4.7	8.5	8.8	13.8	14.4	16.5	Bottom	Bottom	
Elevation (msl) of 15°C Water	1797.2	1784.7	1783.7	1767.3	1765.4	1758.5	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	965,908	1,593,691	1,302,071	693,338	373,449	124,929	0	0	5,053,386
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	249,504	519,262	320,360	312,065	270,879	237,539	123,359	0	2,032,968
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0	0
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1797.2 to Bottom	1784.7 to Bottom	1783.7 to Bottom	1767.3 to Bottom	1765.4 to Bottom	1758.5 to Bottom	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	965,908	1,593,691	1,302,071	693,338	373,449	124,929	0	0	5,053,386
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1812.6 to 1797.2	1803.7 to 1784.7	1795.9 to 1783.7	1782.7 to 1767.3	1780.8 to 1765.4	1776.2 to 1758.5	1769.9 to Bottom	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	249,507	519,262	320,360	312,065	270,879	237,539	123,359	0	2,032,971
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,215,415	2,112,953	1,622,431	1,005,403	644,328	362,468	123,359	0	7,086,357

Note: Lake elevation on June 22, 2005 = 1,812.6 feet-msl. Approximate lake volume on June 22, 2005 = 11,562,586 acre-feet.

Plate 52. Estimate of coldwater habitats present in Lake Sakakawea on July 20, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	22.1	17.9	15.3	17.5	15.3	15.5	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1744.9	1758.7	1767.2	1760	1767.2	1766.5	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	355,090	966,986	913,536	551,787	401,809	220,131	0	0	3,409,339
Depth (meters) of 15°C Water	25.6	29	22.9	18.9	16.4	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1733.4	1722.3	1742.3	1755.4	1763.6	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	257,422	284,650	433,531	465,471	345,089	0	0	0	1,786,163
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	97,668	682,336	480,005	86,316	56,720	220,131	0	0	1,623,176
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	17	15.5	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	1761.6	1766.5	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	0	0	313,577	220,131	0	0	533,708
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1733.6 to Bottom	1722.3 to Bottom	1742.3 to Bottom	1755.4 to Bottom	1763.6 to 1761.6	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	257,422	284,650	433,531	465,471	31,512	0	0	0	1,472,586
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1744.9 to 1733.6	1758.7 to 1722.3	1767.2 to 1742.3	1760.0 to 1755.4	1767.2 to 1763.6	0	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	97,668	682,336	480,005	86,316	56,720	0	0	0	1,403,045
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	355,090	966,986	913,536	551,787	88,232	0	0	0	2,875,631

Note: Lake elevation on July 20, 2005 = 1,817.4 feet-msl. Approximate lake volume on July 20, 2005 = 12,692,233 acre-feet.

Plate 53. Estimate of coldwater habitats present in Lake Sakakawea on August 24, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	18.2	19.7	21.4	18.3	20.4	17.2	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1756.5	1751.6	1746	1756.2	1749.3	1759.8	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 18.3°C	465,629	813,964	497,571	480,482	145,289	136,416	0	0	2,539,351
Depth (meters) of 15°C Water	25	25.3	24.7	22.2	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1734.2	1733.2	1735.2	1743.4	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	263,876	461,670	317,329	248,355	0	0	0	0	1,291,230
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	201,753	352,294	180,242	232,127	145,289	136,416	0	0	1,248,121
Depth of 5 mg/l DO Water	Bottom	Bottom	23.8	22.2	20.1	17.5	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	1738.1	1743.4	1750.3	1758.8	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	0	0	363,483	248,355	156,330	127,075	0	0	895,243
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	1734.2 to Bottom	1733.2 to Bottom	0	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	263,876	461,670	0	0	0	0	0	0	725,546
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1756.5 to 1734.2	1751.6 to 1733.2	1746.0 to 1738.1	1756.2 to 1743.4	0	1759.8 to 1758.8	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	201,753	352,294	134,088	232,127	0	9,341	0	0	929,603
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	465,629	813,964	134,088	232,127	0	9,341	0	0	1,655,149

Note: Lake elevation on August 24, 2005 = 1,816.2 feet-msl. Approximate lake volume on August 24, 2005 = 12,408,823 acre-feet.

Plate 54. Estimate of coldwater habitats present in Lake Sakakawea on September 19, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1814.8	1814.8	1814.8	1814.8	1814.8	1814.8	1814.8	1814.8	
Volume (ac-ft) of Water ≤ 18.3°C	1,254,430	2,441,700	2,164,594	1,733,598	1,454,415	1,379,686	1,067,119	582,967	12,078,509
Depth (meters) of 15°C Water	31.7	31.8	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation (msl) of 15°C Water	1710.8	1710.5	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 15°C	99,735	127,516	0	0	0	0	0	0	227,251
Volume (ac-ft) of Water > 15°C and ≤ 18.3°C	1,154,695	2,314,184	2,164,594	1,733,598	1,454,415	1,379,686	1,067,119	582,967	11,851,258
Depth of 5 mg/l DO Water	30.8	31.3	30.2	-----	23.4	-----	Bottom	Bottom	
Elevation of 5 mg/l DO Water	1713.7	1712.1	1715.7	1726.9*	1738	1738.0*	Bottom	Bottom	
Volume (ac-ft) of Water ≤ 5mg/l DO	118,050	147,929	61,136	44,574	43,040	8,124	0	0	422,853
Thickness of Optimal Coldwater Habitat Layer (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	0	0	0	0	0	0	0	0	
Volume (acre-ft) of Optimal Coldwater Habitat (i.e., ≤ 15°C, and ≥ 5 mg/l DO)	0	0	0	0	0	0	0	0	0
Thickness of Marginal Coldwater Habitat Layer (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1814.8 to 1713.7	1814.8 to 1712.1	1814.8 to 1715.7	1814.8 to 1726.9	1814.8 to 1738.0	1814.0 to 1738.0	1814.8 to Bottom	1814.8 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., > 15°C and ≤ 18.3°C, and ≥ 5 mg/l DO)	1,136,380	2,293,771	2,103,458	1,689,024	1,411,375	1,371,562	1,067,119	582,967	11,655,656
Volume (acre-ft) of Total Coldwater Habitat (i.e., ≤ 18.3°C, and ≥ 5 mg/l DO)	1,136,380	2,293,771	2,103,458	1,689,024	1,411,375	1,371,562	1,067,119	582,967	11,655,656

* Elevation estimated from depth-profile measurements taken at adjacent stations.

Note: Lake elevation on September 19, 2005 = 1814.8 feet-msl. Approximate lake volume on September 19, 2005 = 12,078,510 acre-feet.

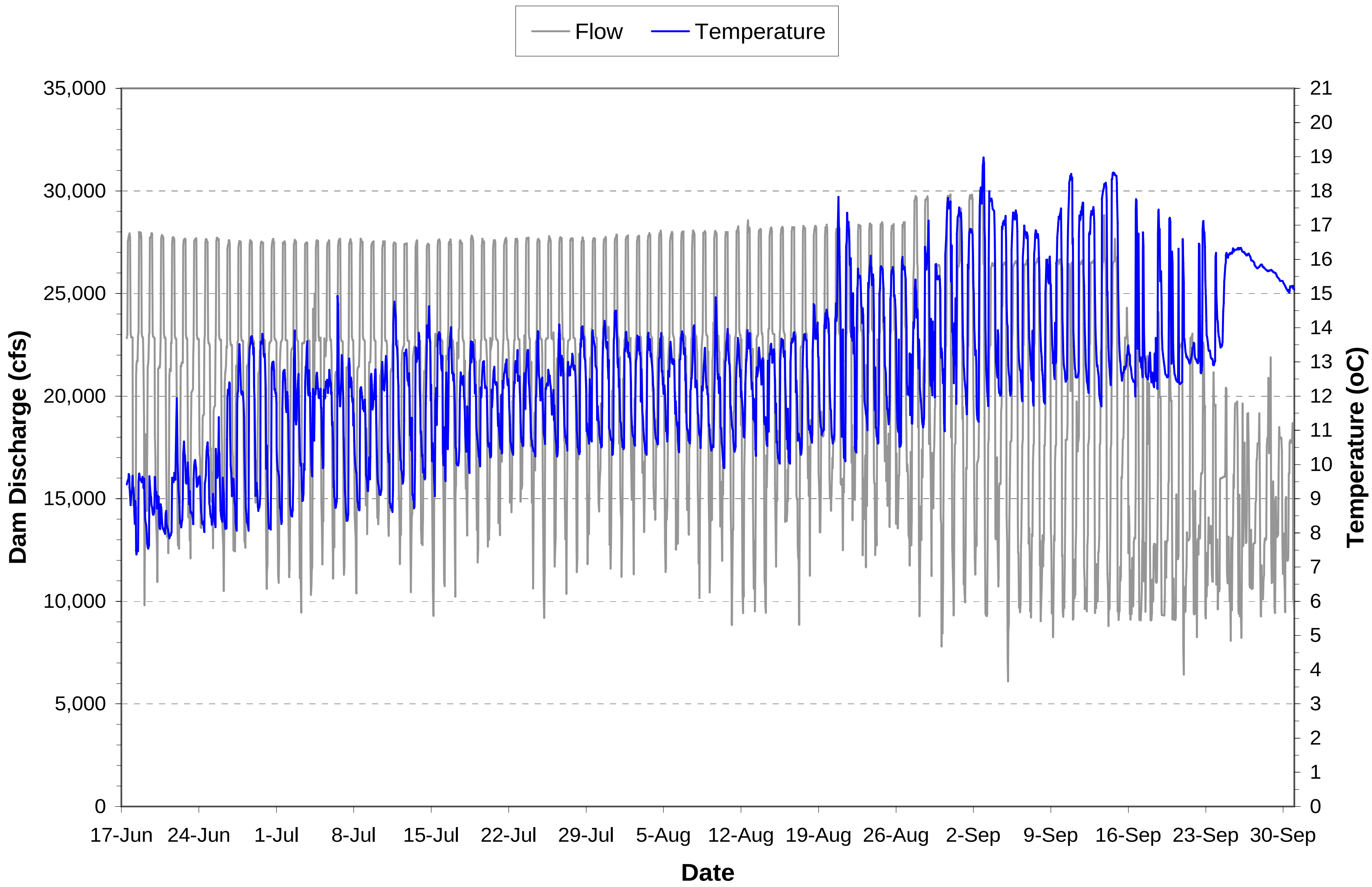

Plate 55. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period June 17, 2003 through September 30, 2003.

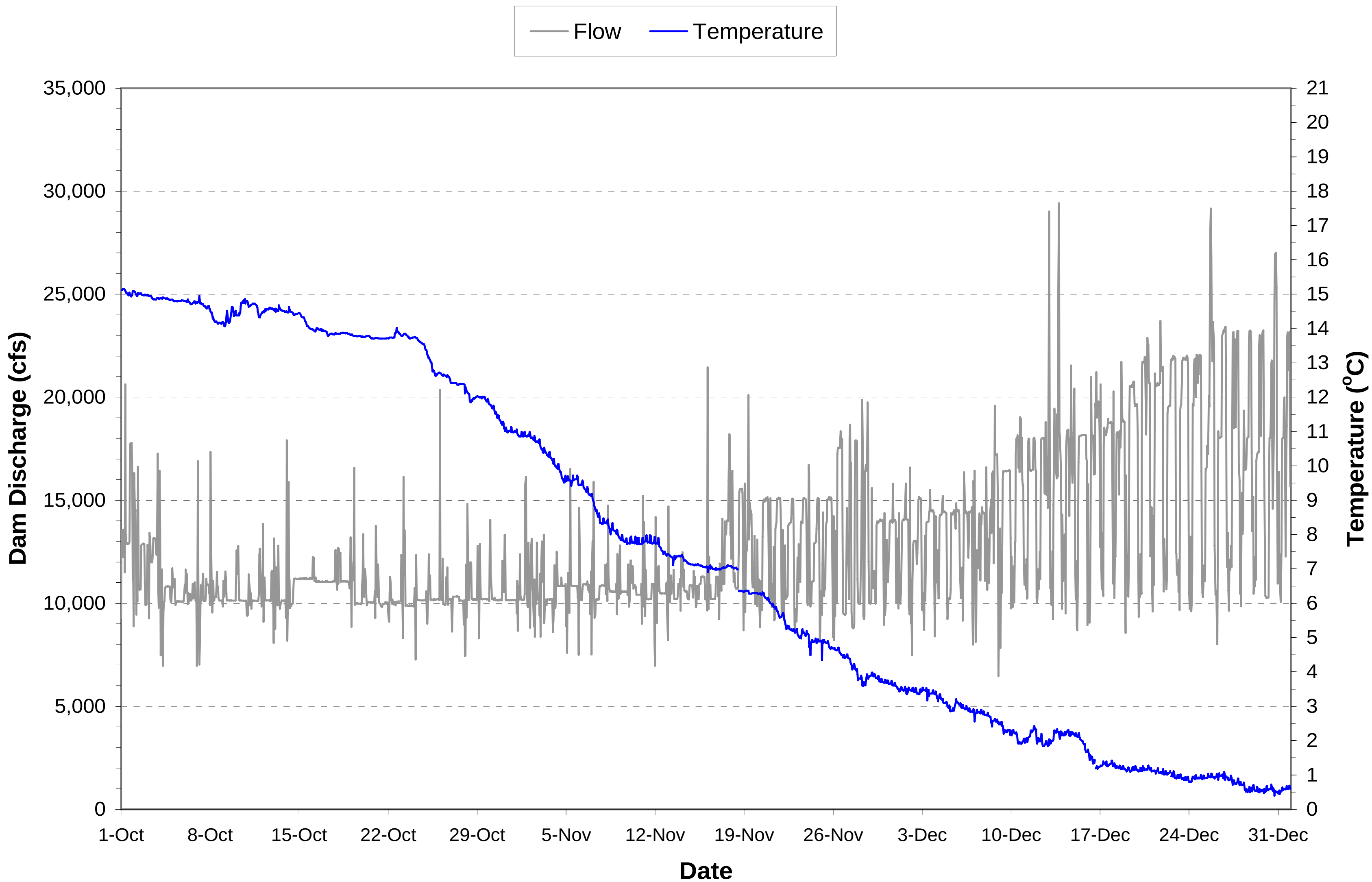

Plate 56. Hourly discharge and water temperature monitored in the “raw water loop” at the Garrison powerhouse during the period October 1, 2003 through December 31, 2003.

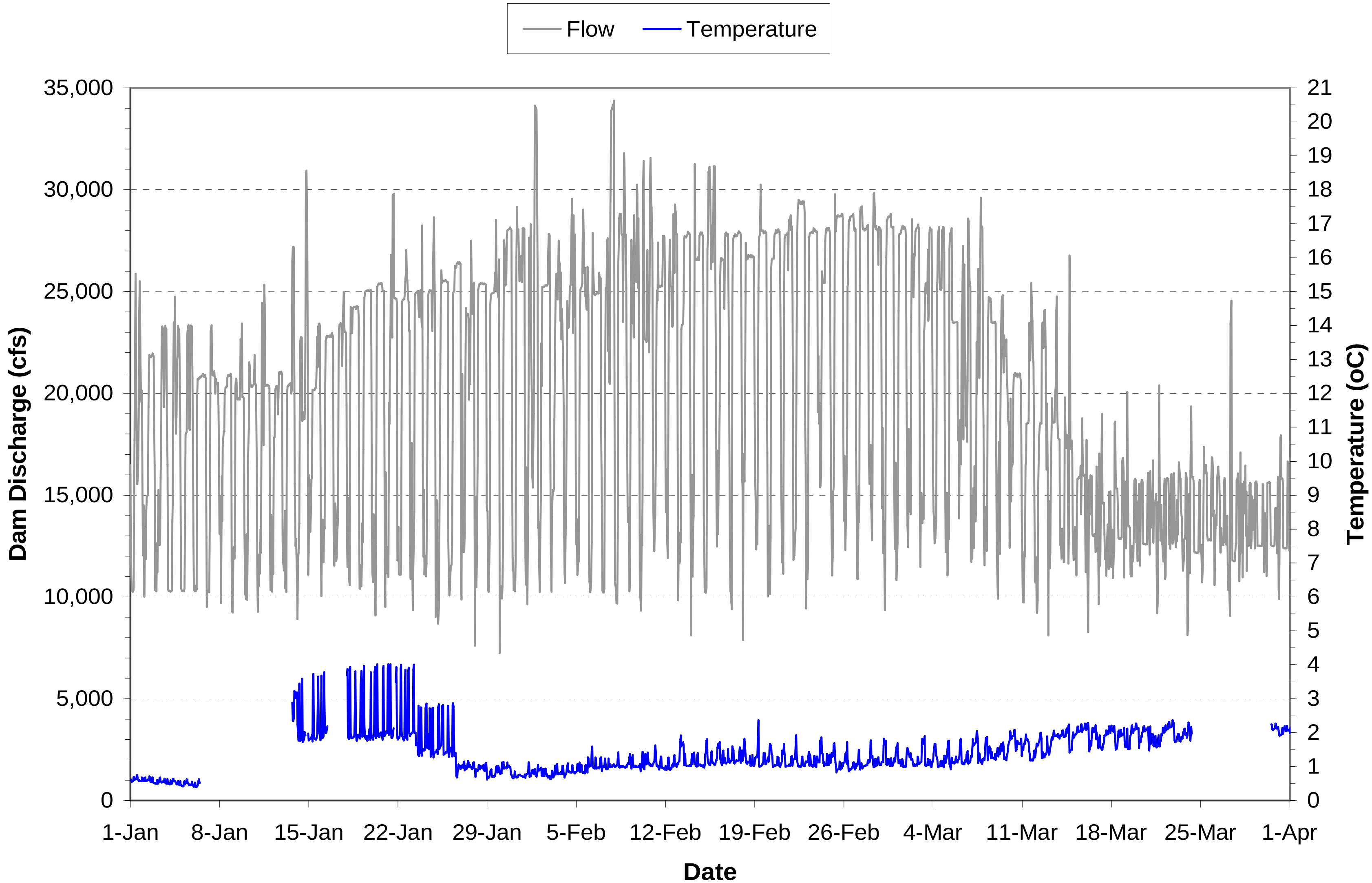

Plate 57. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period January 1, 2004 through March 31, 2004

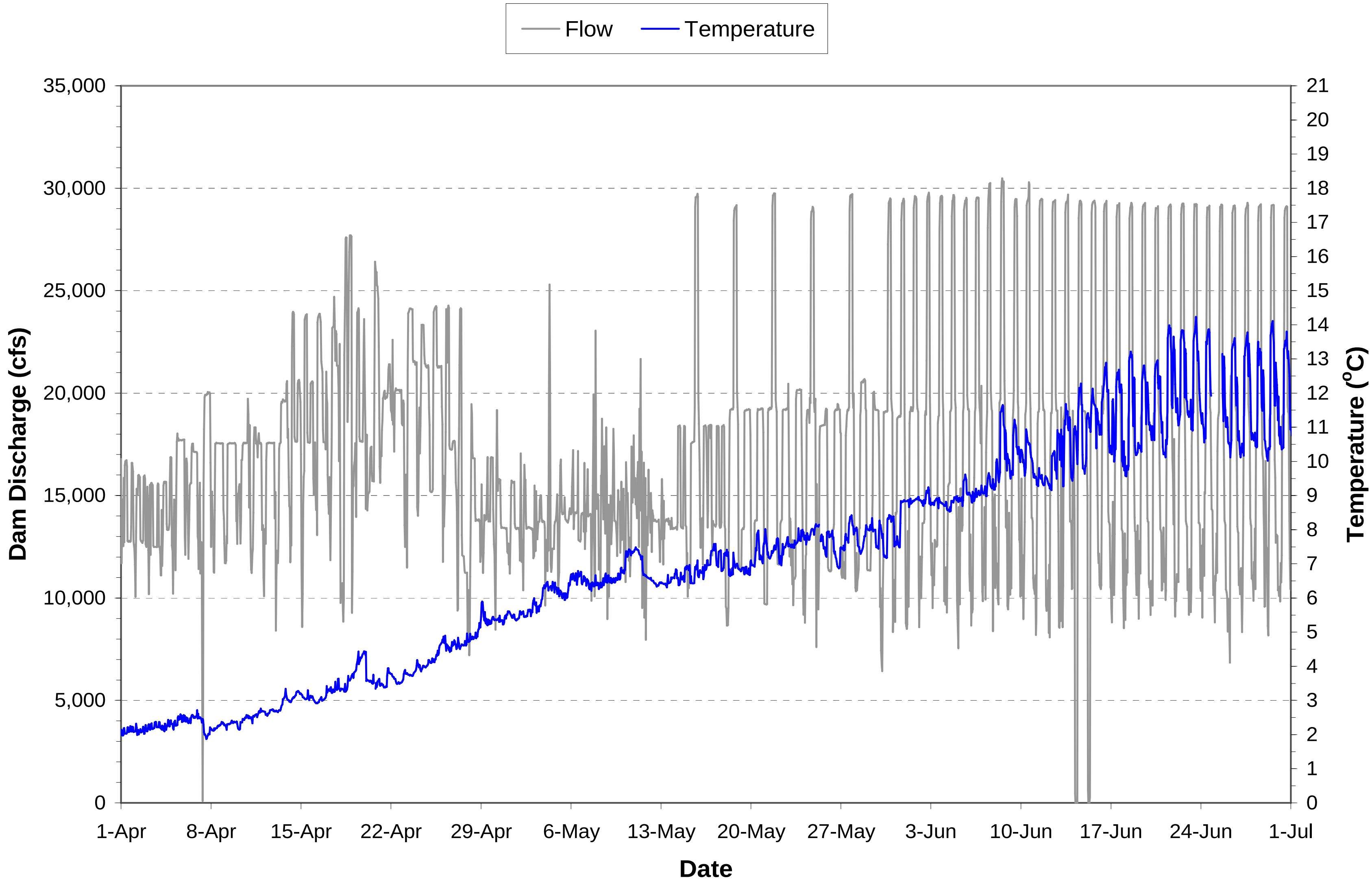

Plate 58. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period April 1, 2004 through June 30, 2004.

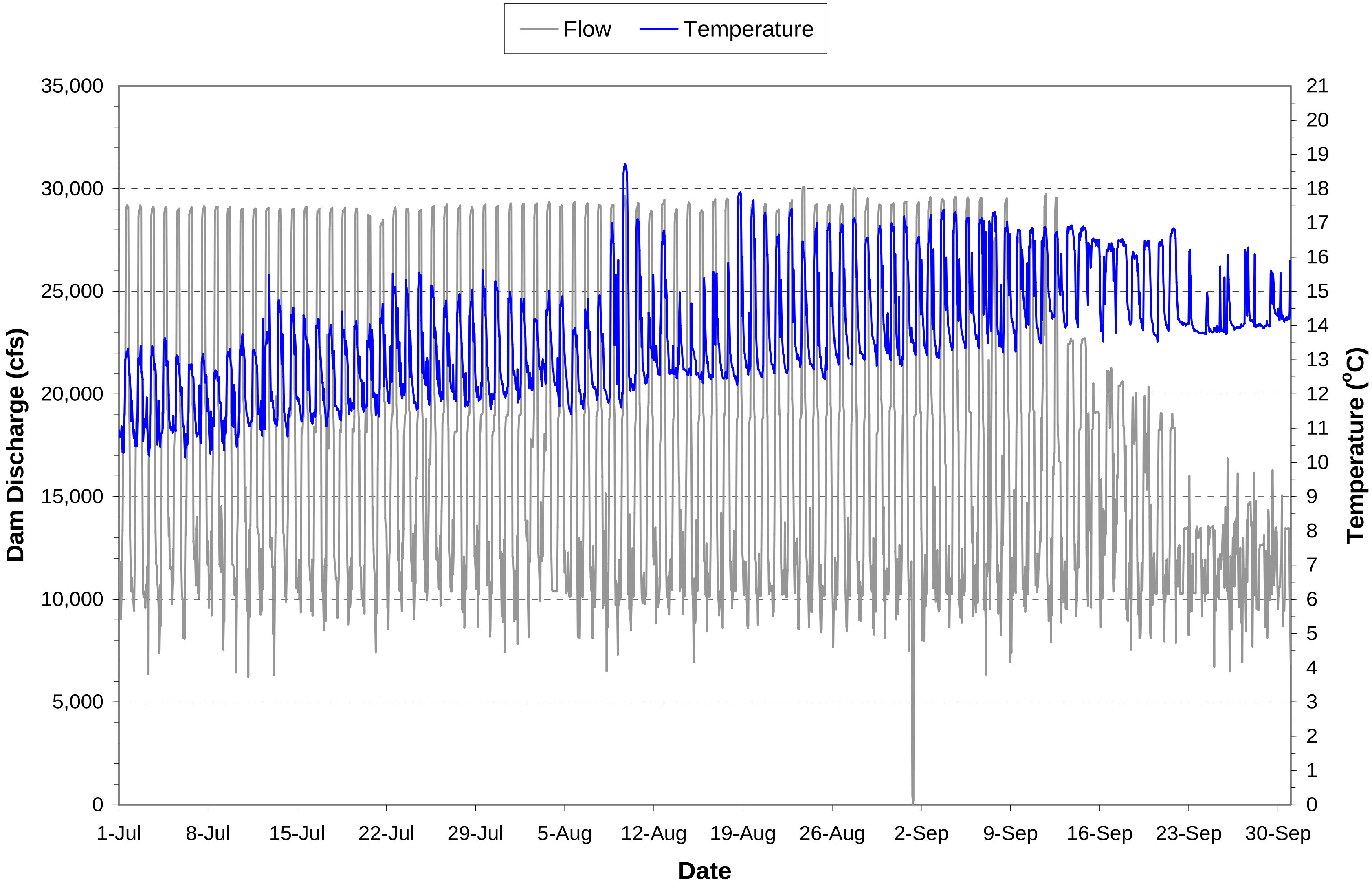

Plate 59. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period July 1, 2004 through September 30, 2004.

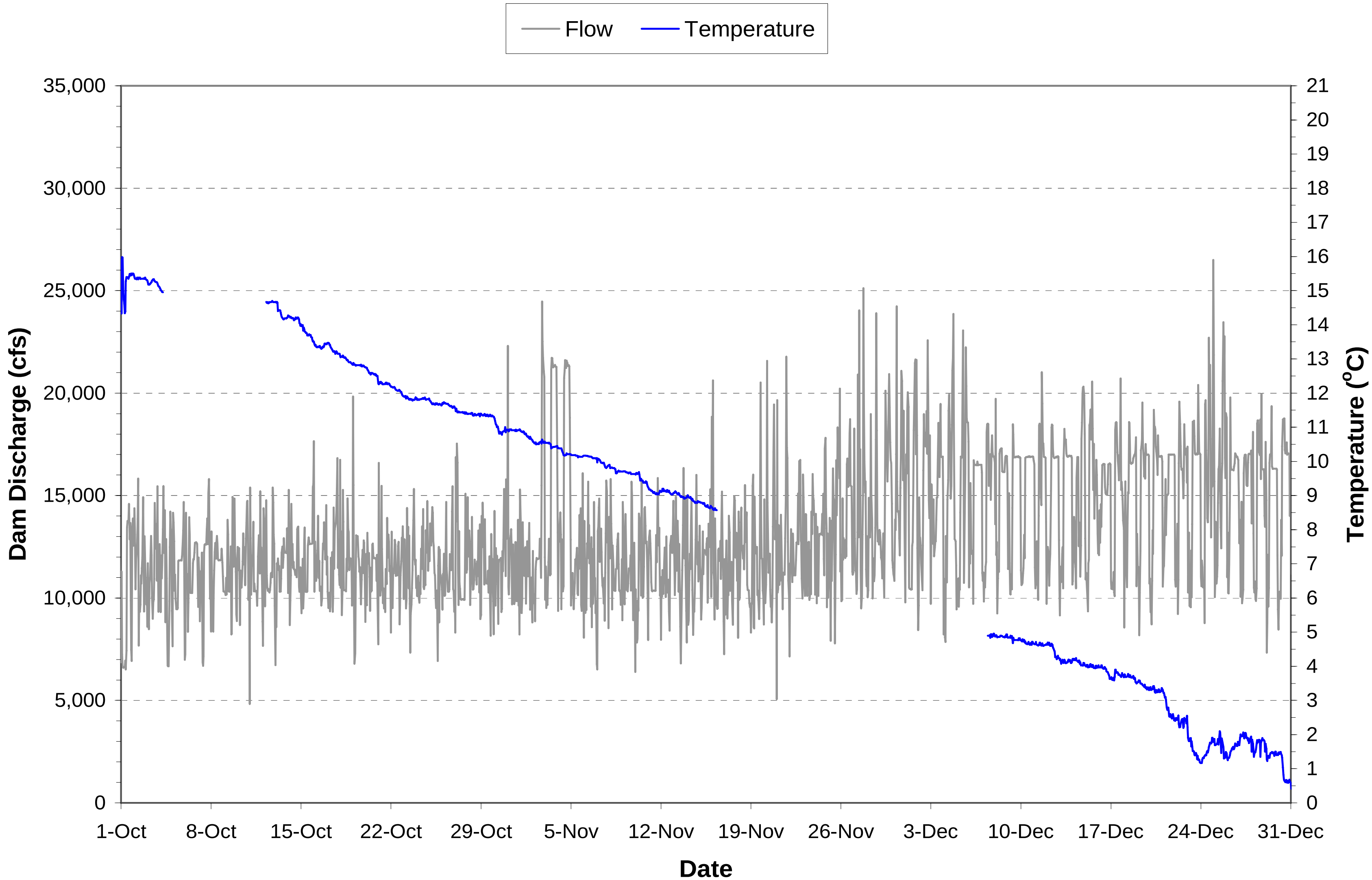

Plate 60. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period October 1, 2004 through December 31, 2004.

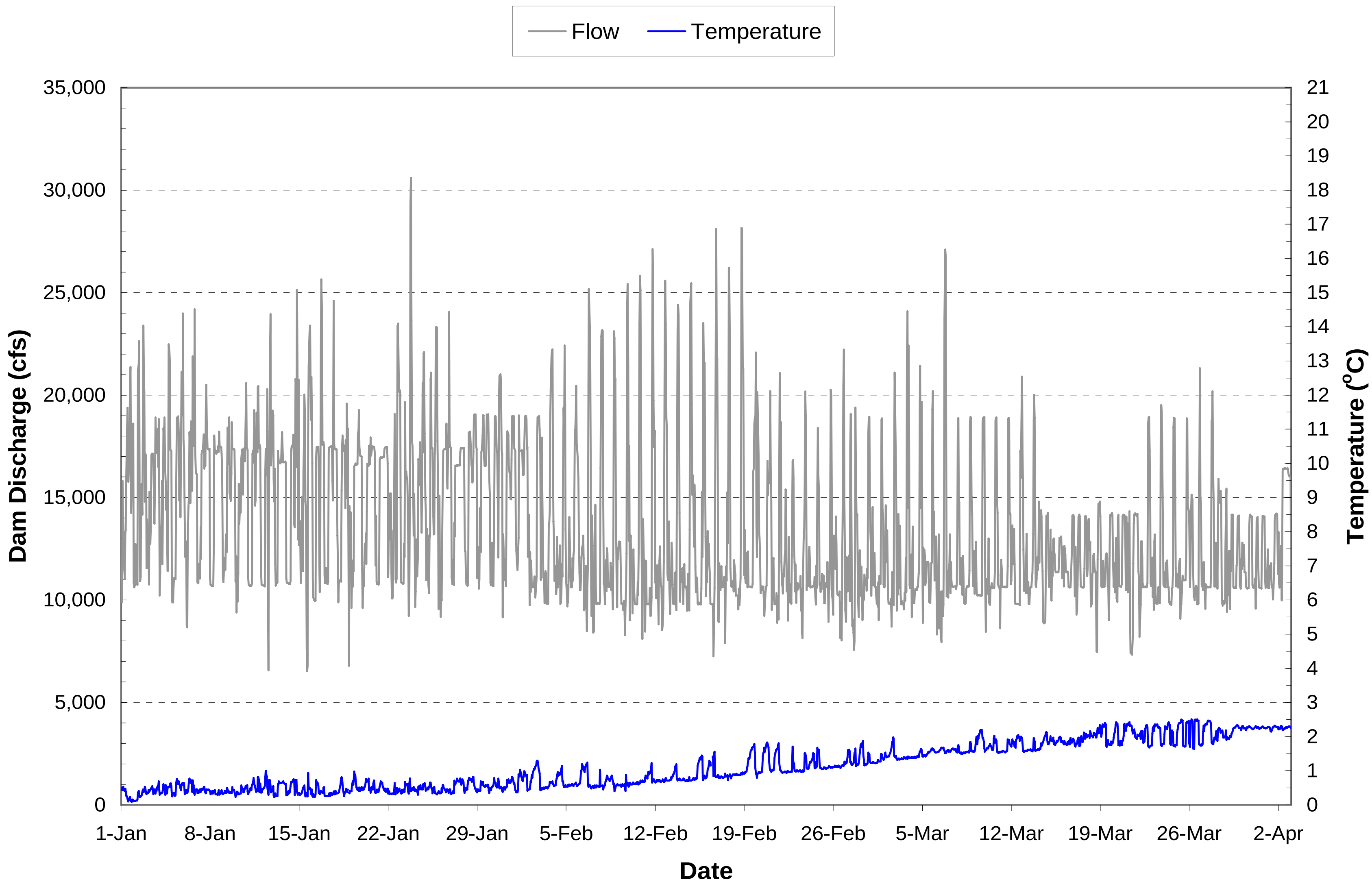

Plate 61. Hourly discharge and water temperature monitored in the “raw water loop” at the Garrison powerhouse during the period January 1, 2005 through March 31, 2005.

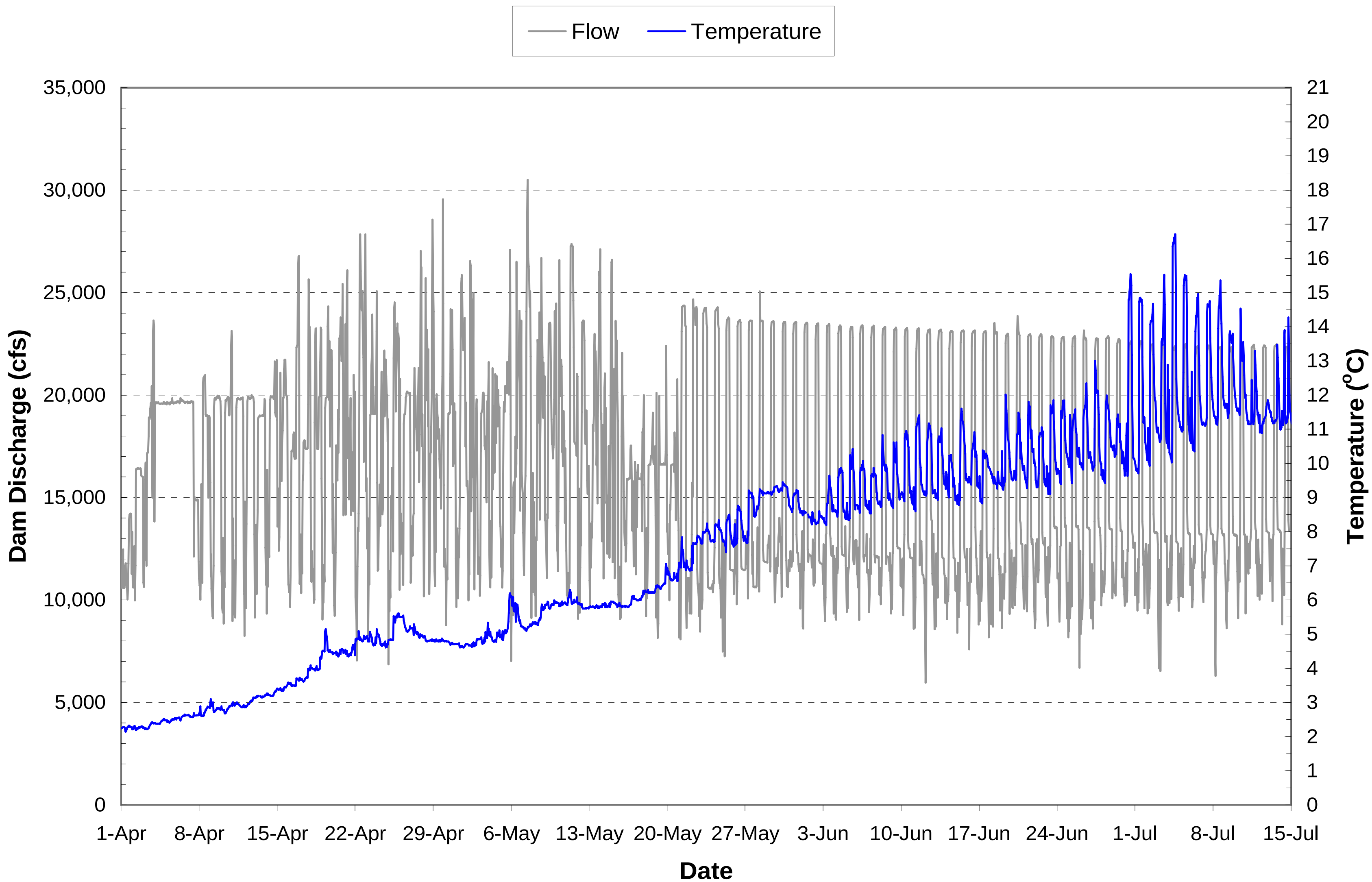

Plate 62. Hourly discharge and water temperature monitored in the "raw water loop" at the Garrison powerhouse during the period April 1, 2005 through July 15, 2005.

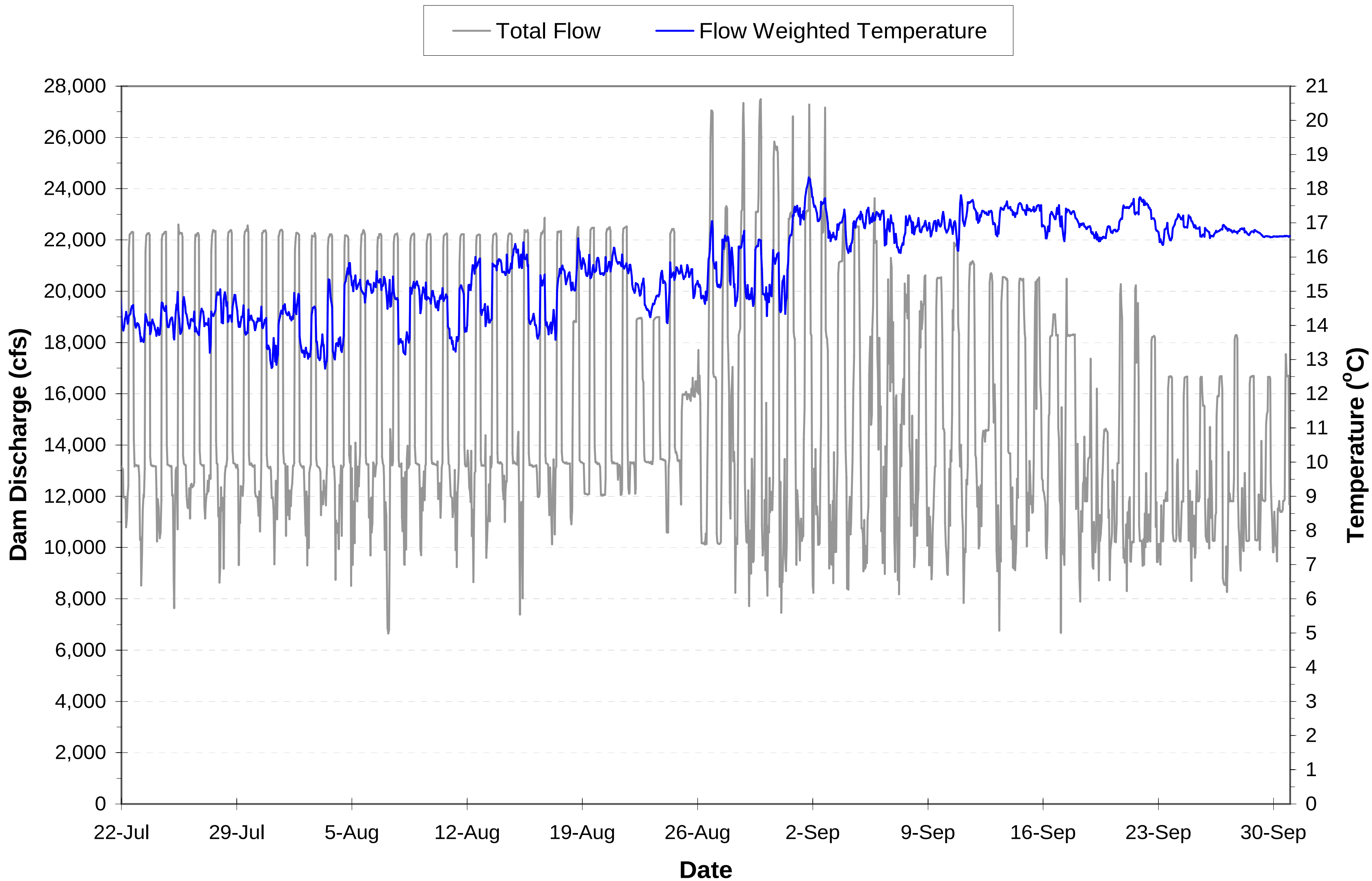

Plate 63. Hourly discharge and flow-weighted average water temperature of water passed through Garrison Dam based on monitoring of the dam's five individual penstocks during the period July 22, 2005 through September 30, 2005.

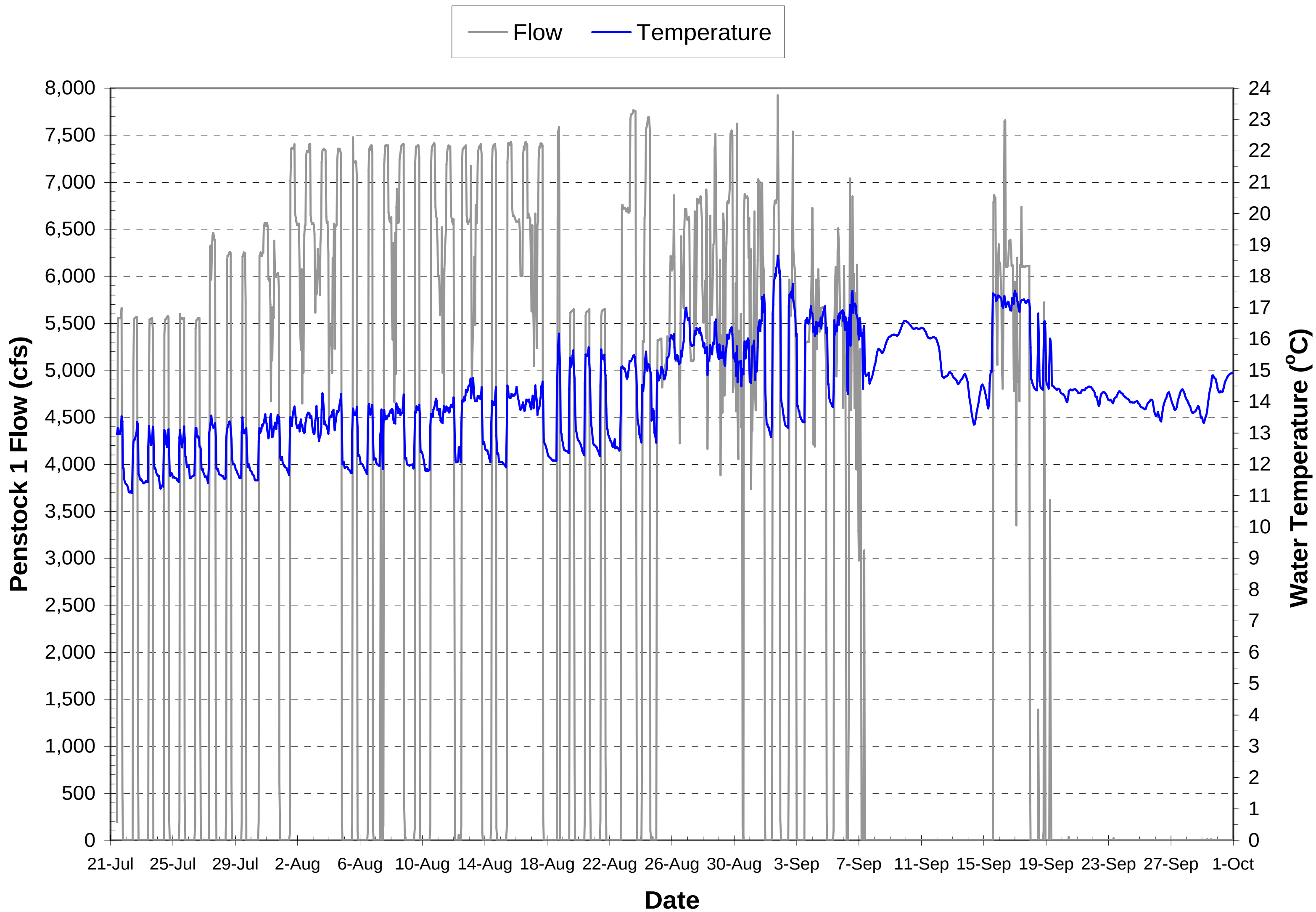

Plate 64. Average hourly discharge and water temperature measured in penstock 1 during the period July 21, 2005 through September 30, 2005.

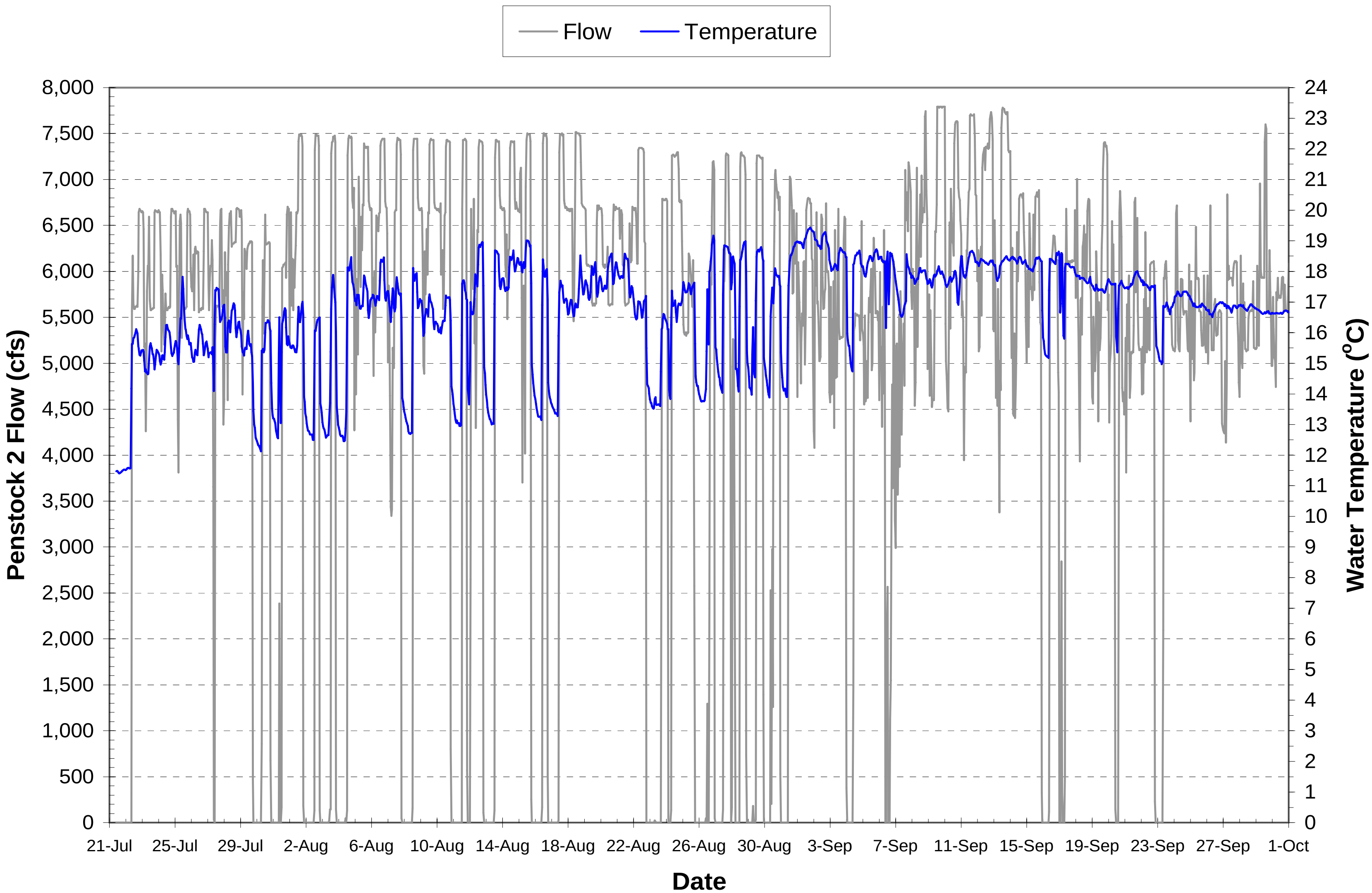

Plate 65. Average hourly discharge and water temperature measured in penstock 2 during the period July 21, 2005 through September 30, 2005.

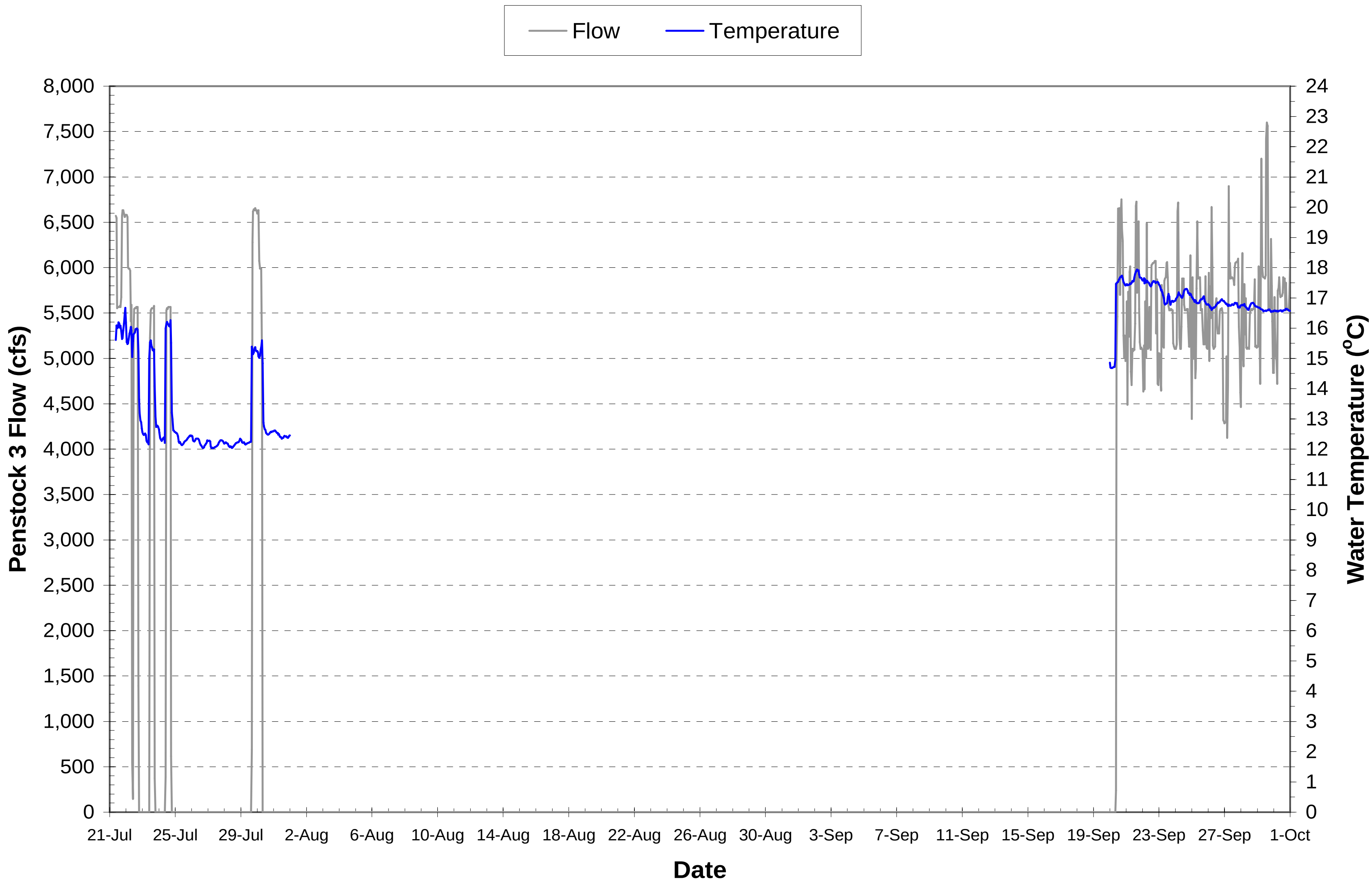

Plate 66. Average hourly discharge and water temperature measured in penstock 3 during the period July 21, 2005 through September 30, 2005.

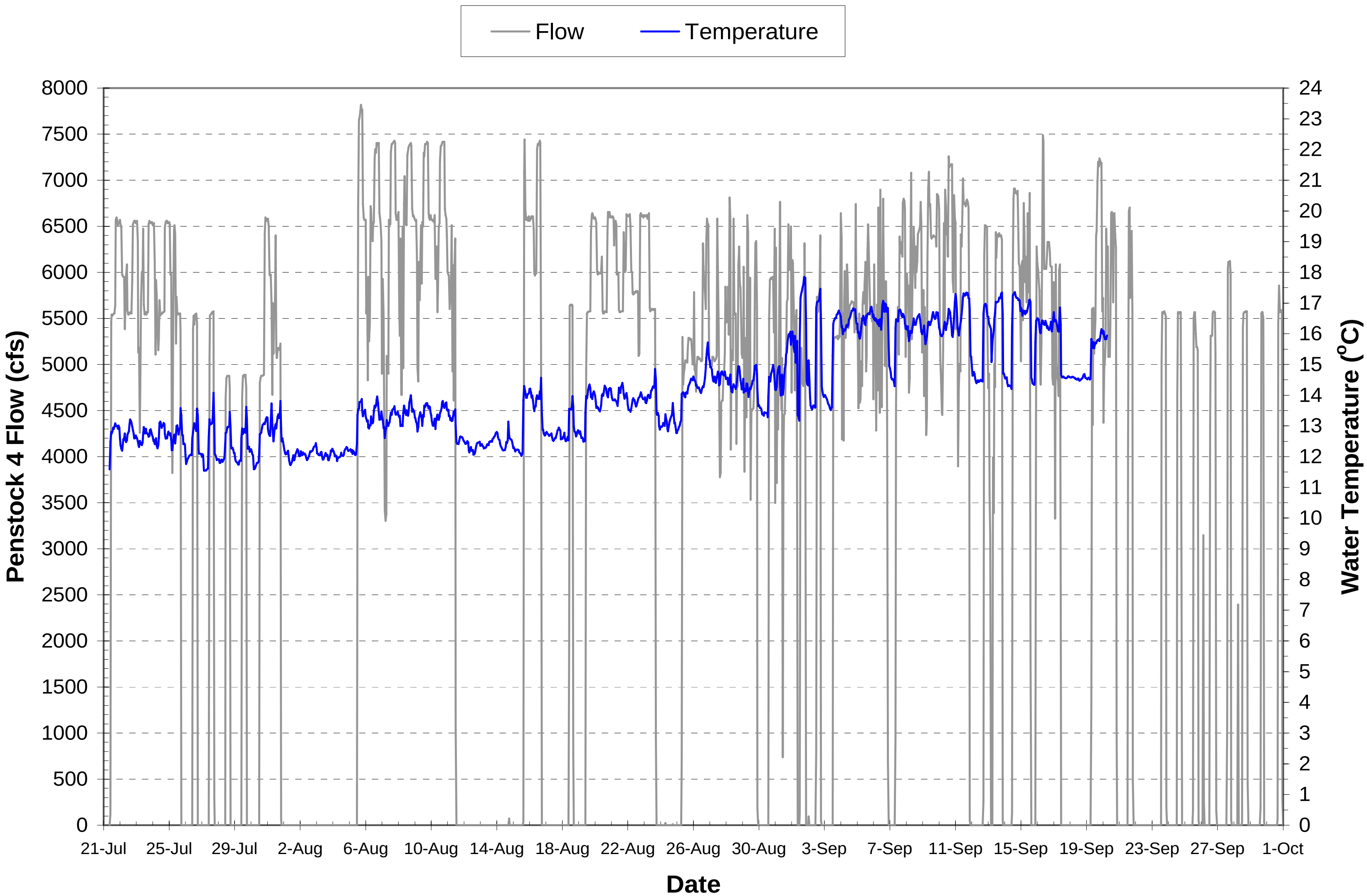

Plate 67. Average hourly discharge and water temperature measured in penstock 4 during the period July 21, 2005 through September 30, 2005. (Note: Data-logger malfunctioned and no water quality data collected after September 19th.)

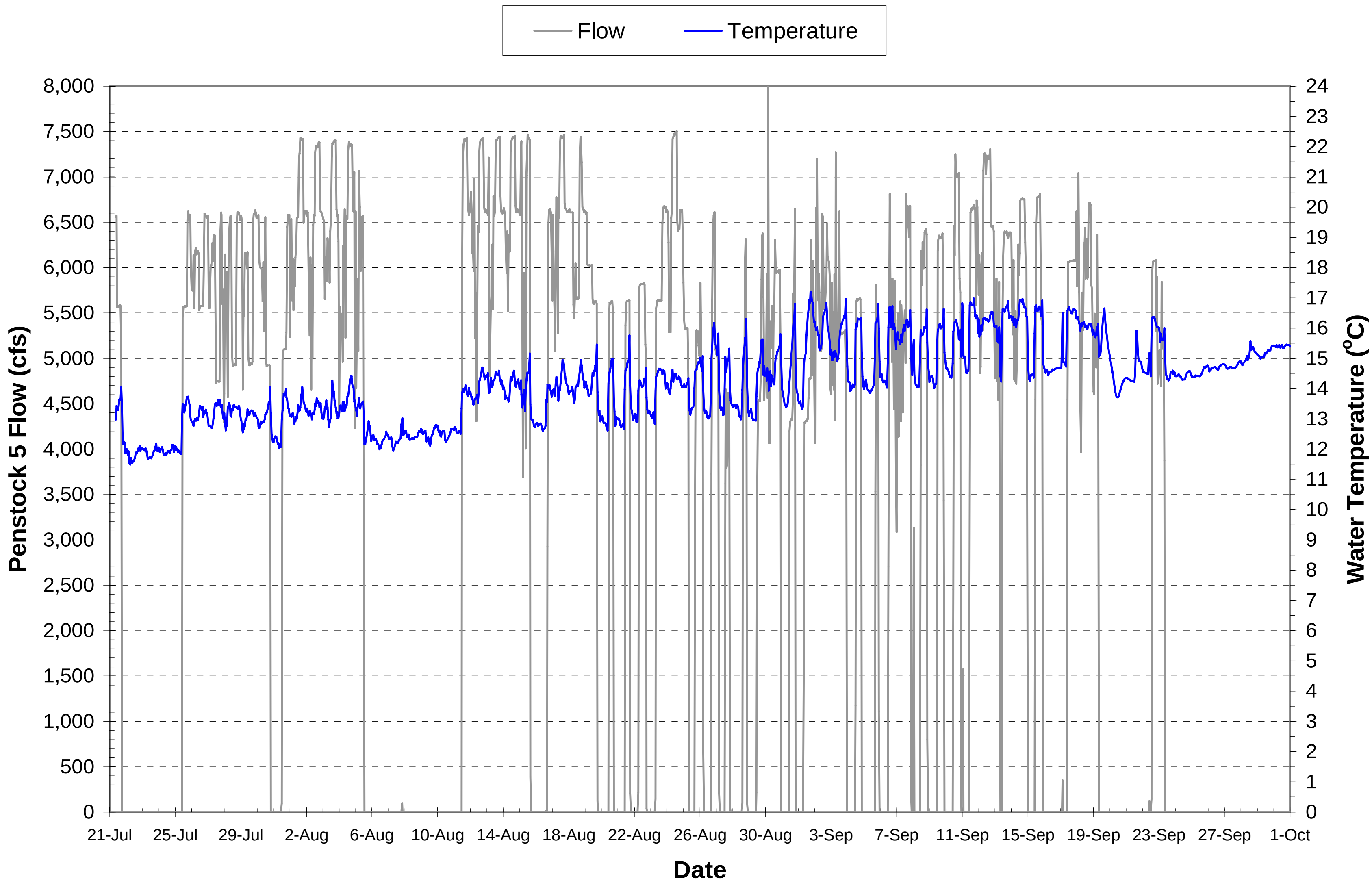

Plate 68. Average hourly discharge and water temperature measured in penstock 5 during the period July 21, 2005 through September 30, 2005.

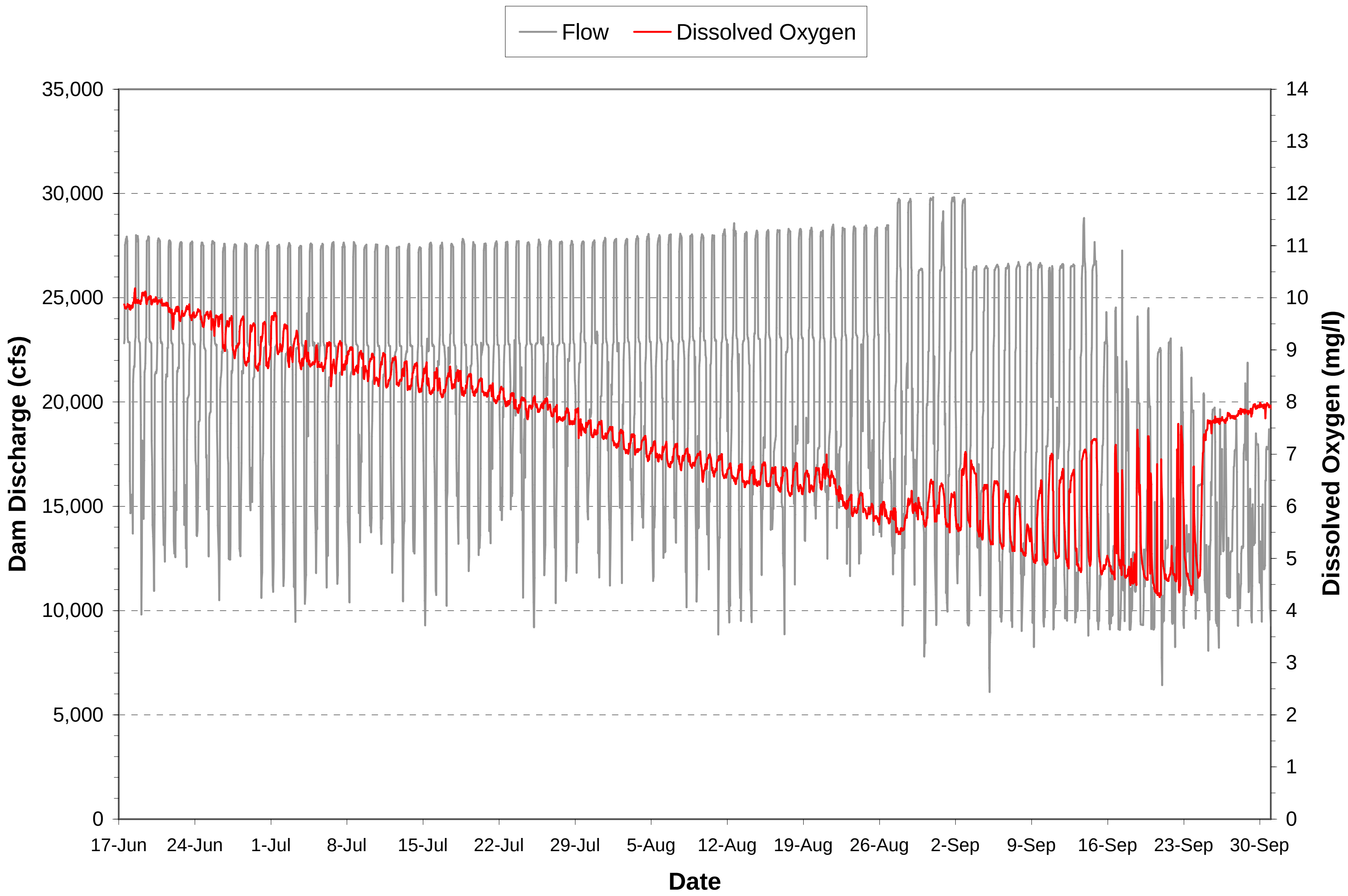

Plate 69. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period June 17, 2003 through September 30, 2003.

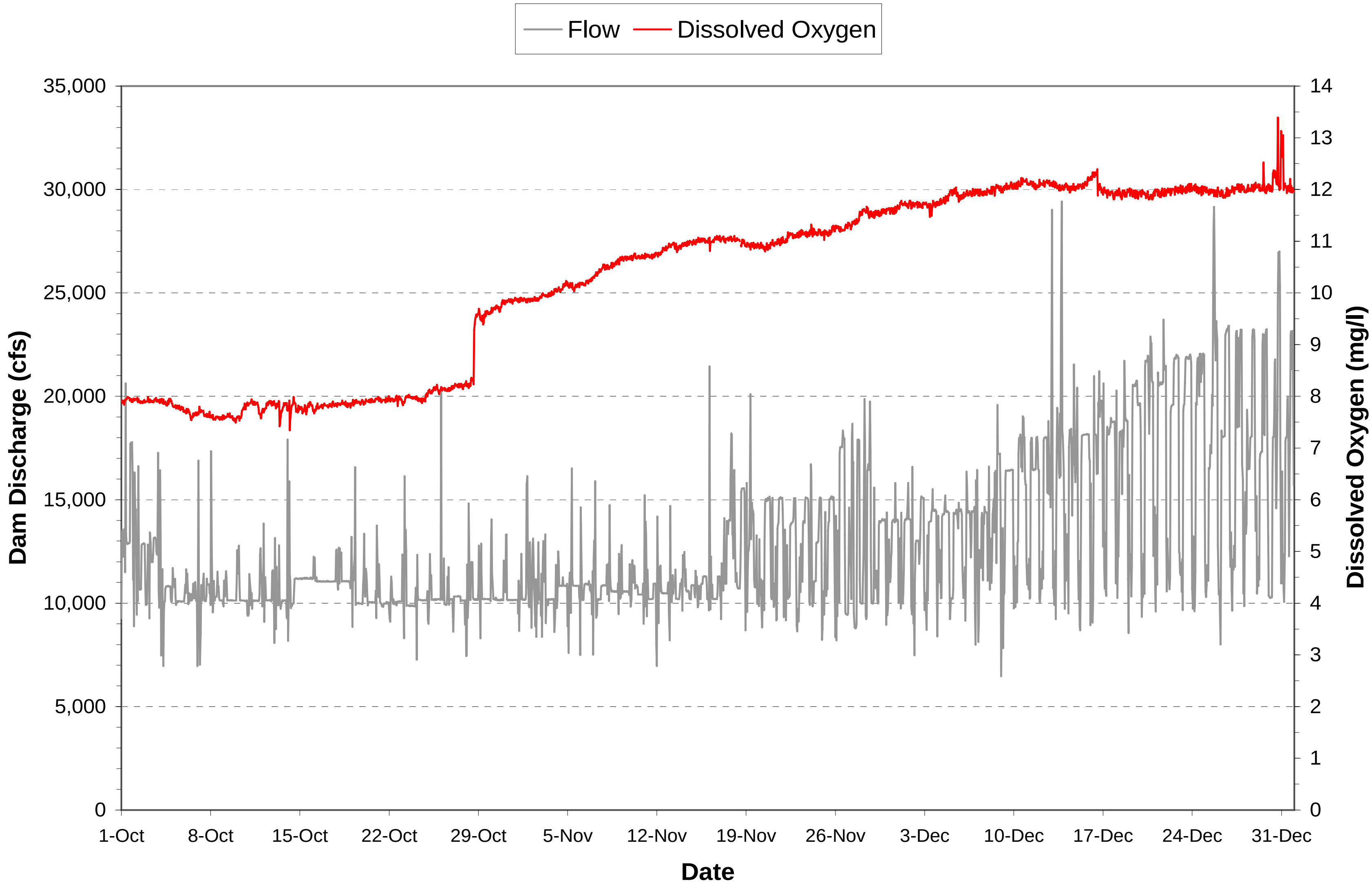

Plate 70. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period October 1, 2003 through December 31, 2003.

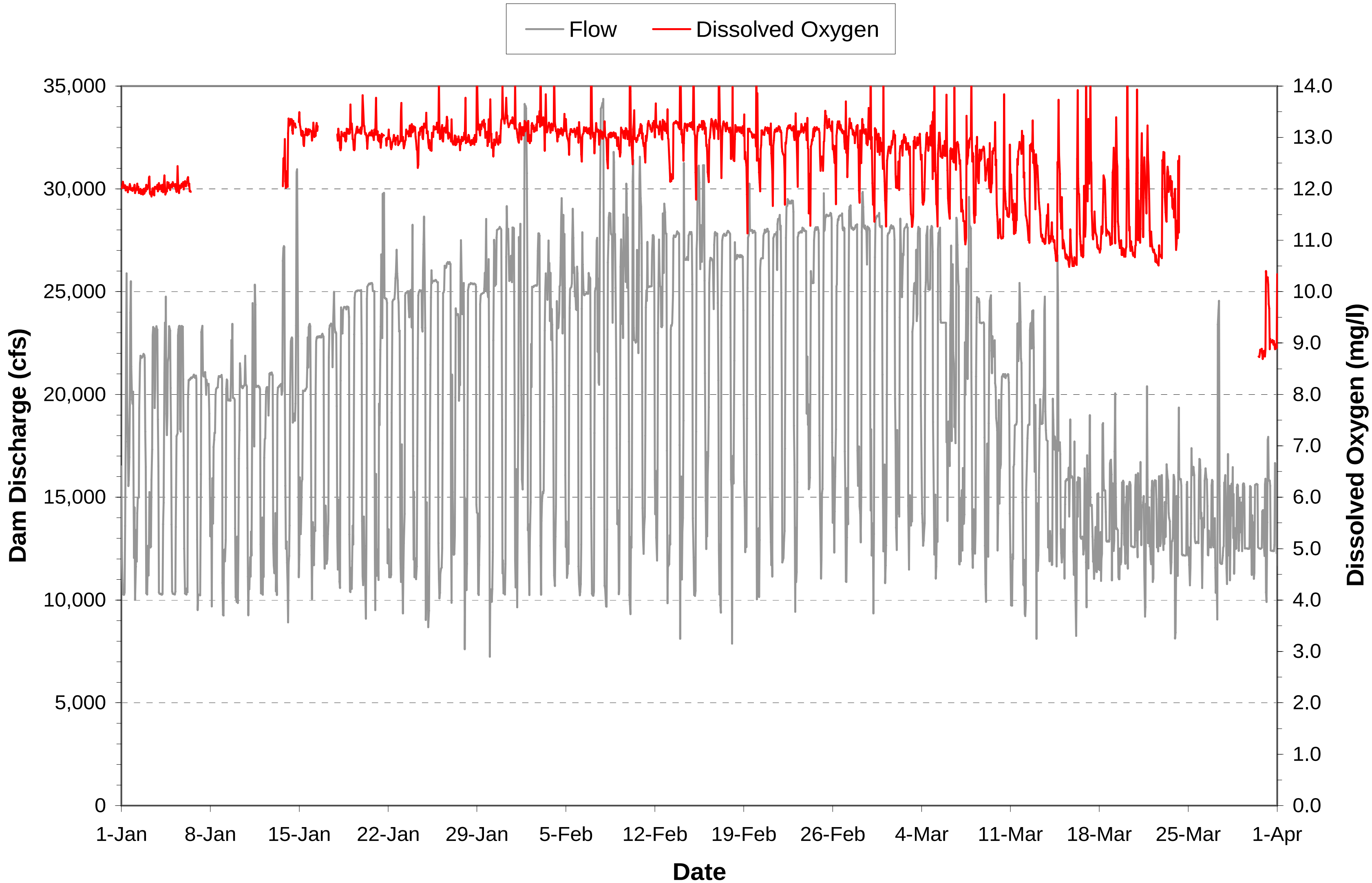

Plate 71. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period January 1, 2004 through March 31, 2004.

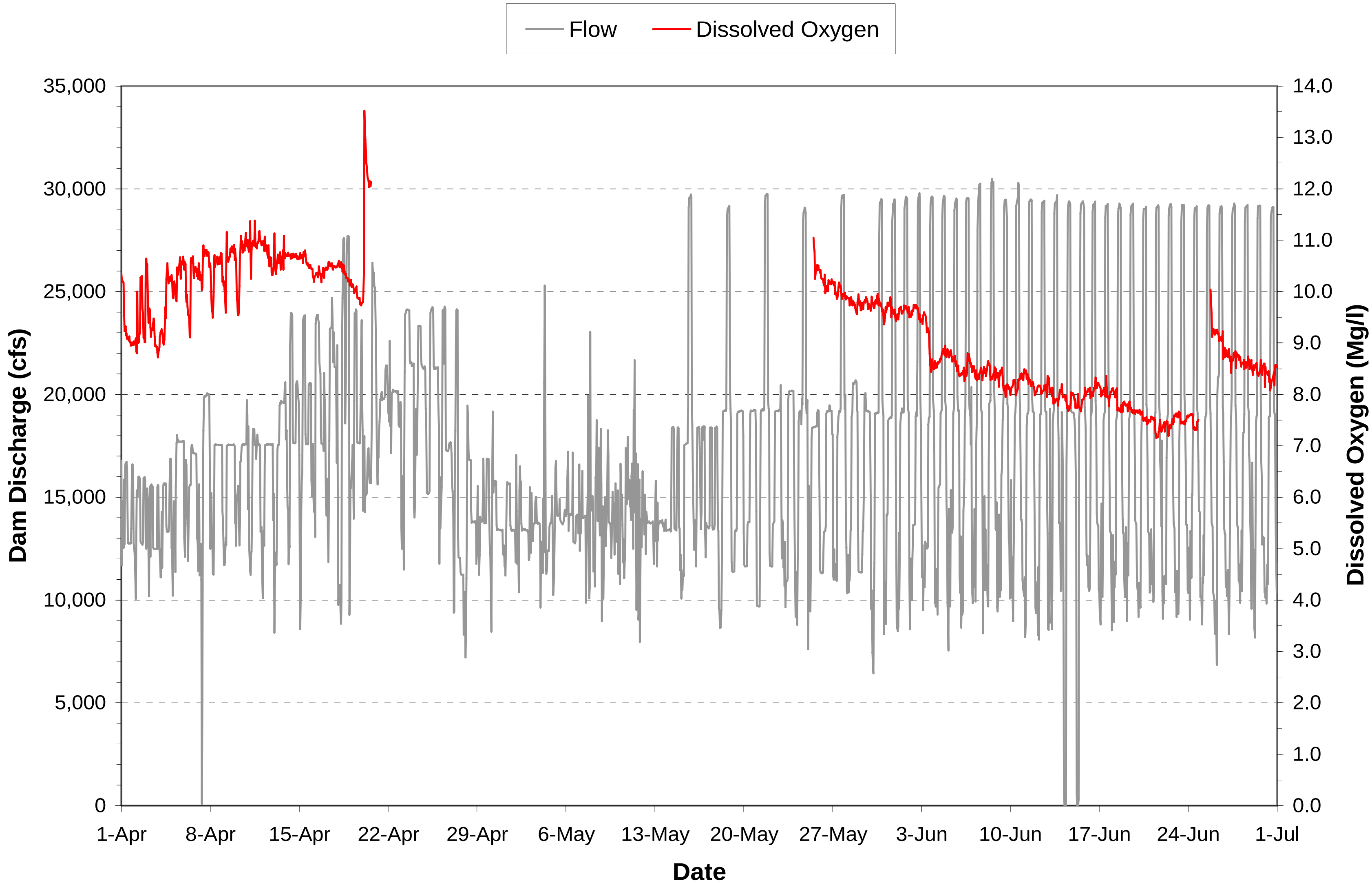

Plate 72. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period April 1, 2004 through June 30, 2004.

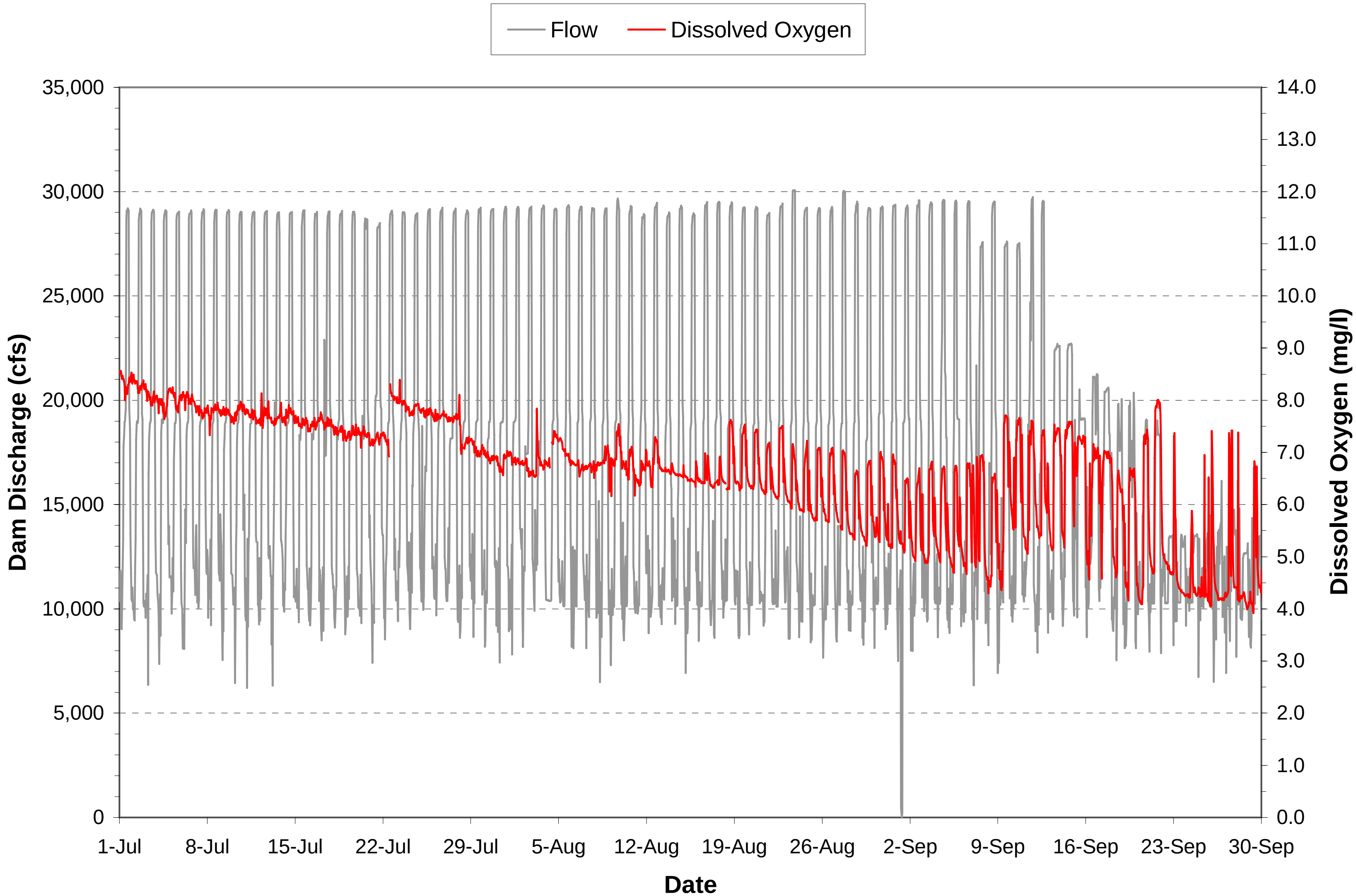

Plate 73. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period July 1, 2004 through September 30, 2004.

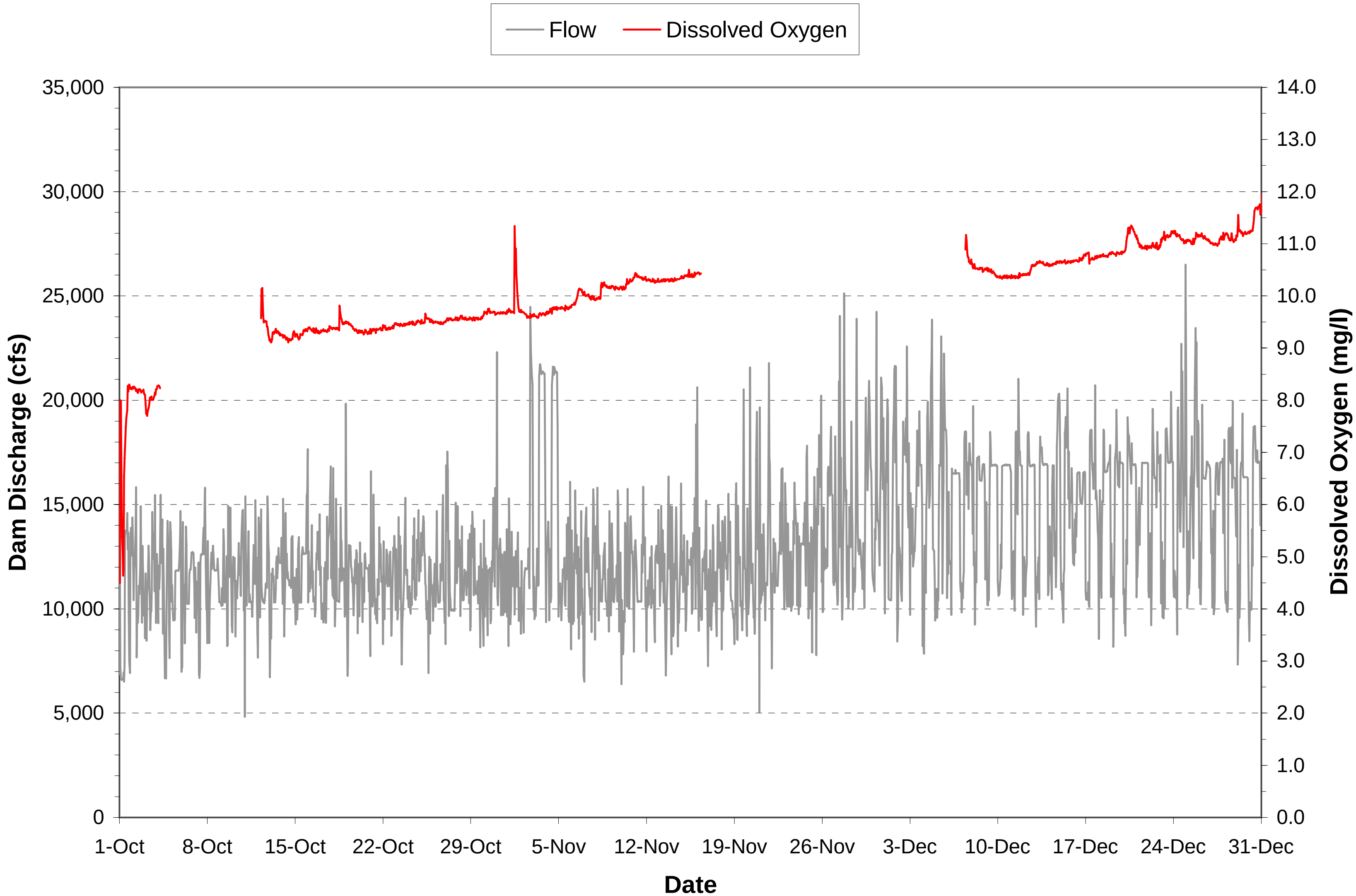

Plate 74. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period October 1, 2004 through December 31, 2004.

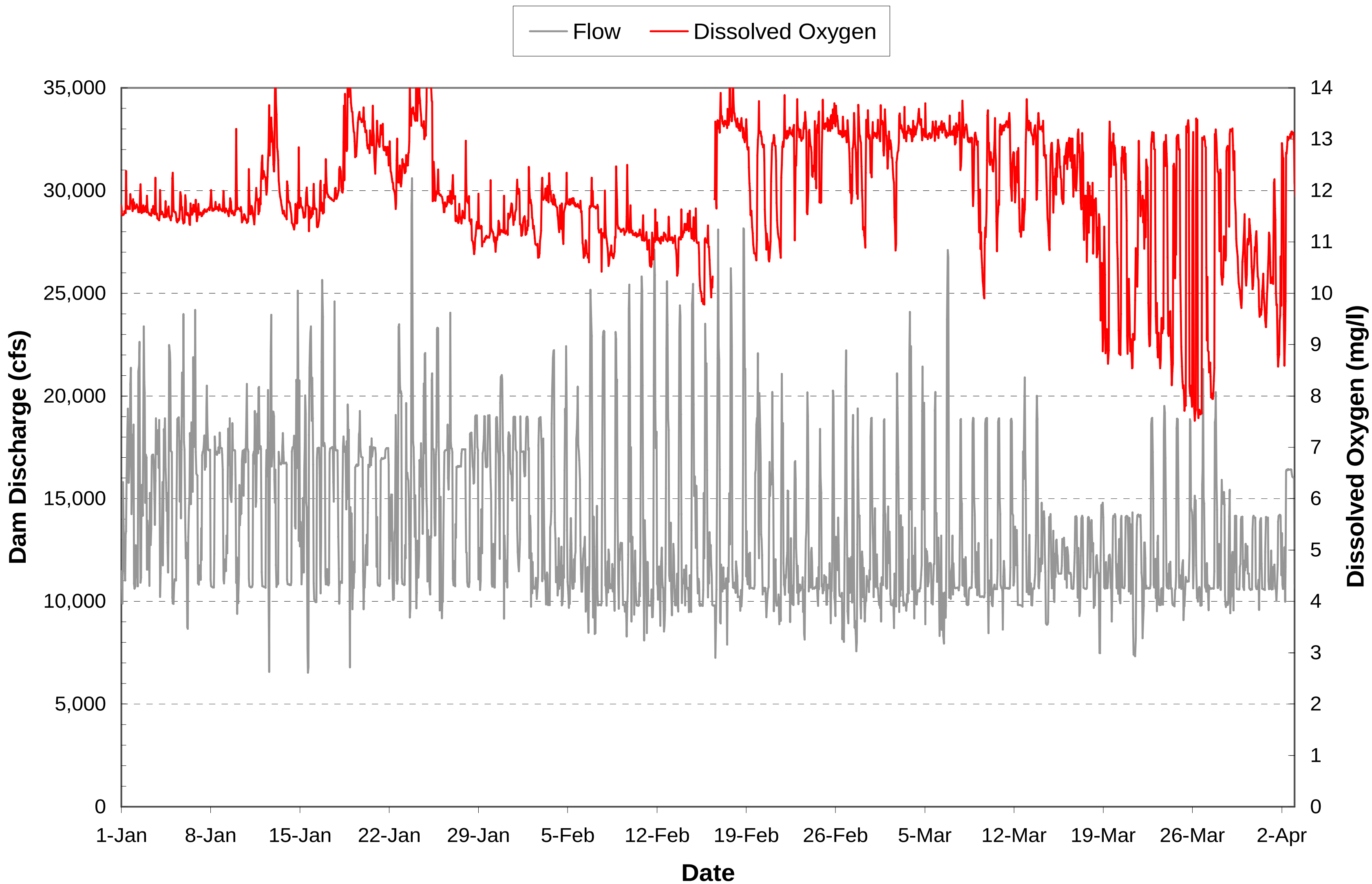

Plate 75. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period January 1, 2005 through March 31, 2005.

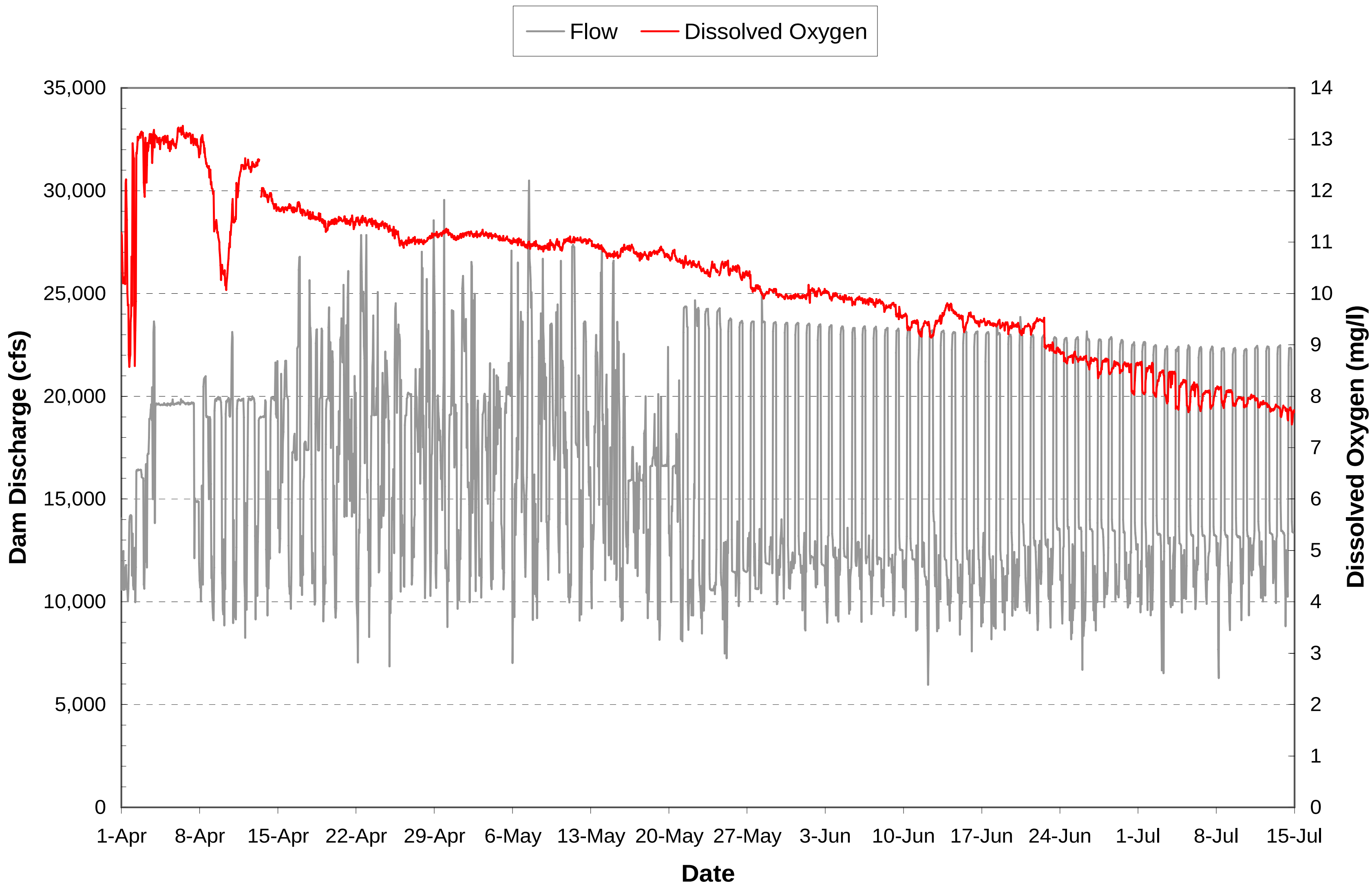

Plate 76. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water loop" at the Garrison powerhouse during the period April 1, 2005 through July 15, 2005.

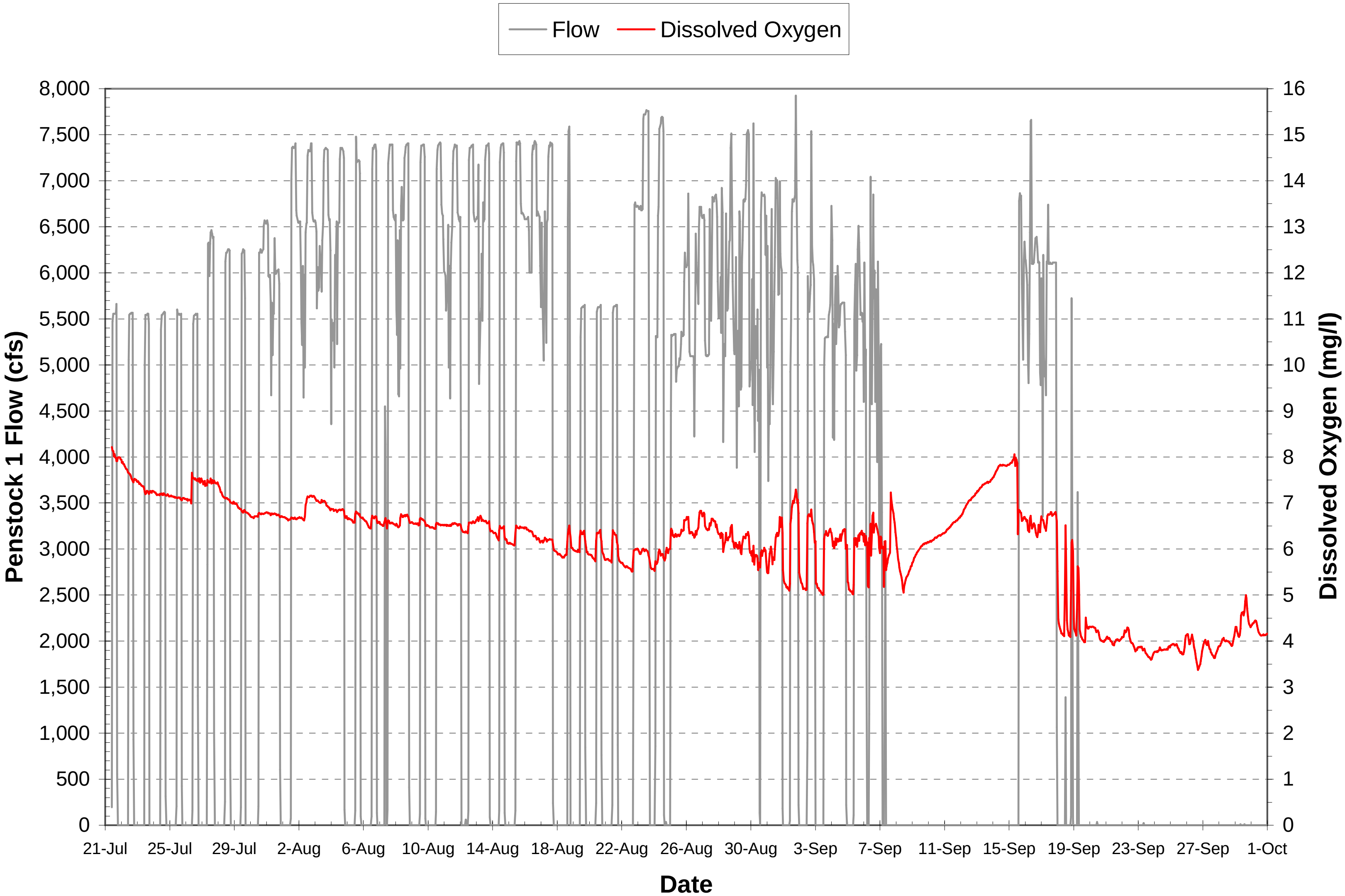

Plate 77. Average hourly discharge and dissolved oxygen concentrations measured in penstock 1 during the period July 21, 2005 through September 30, 2005.

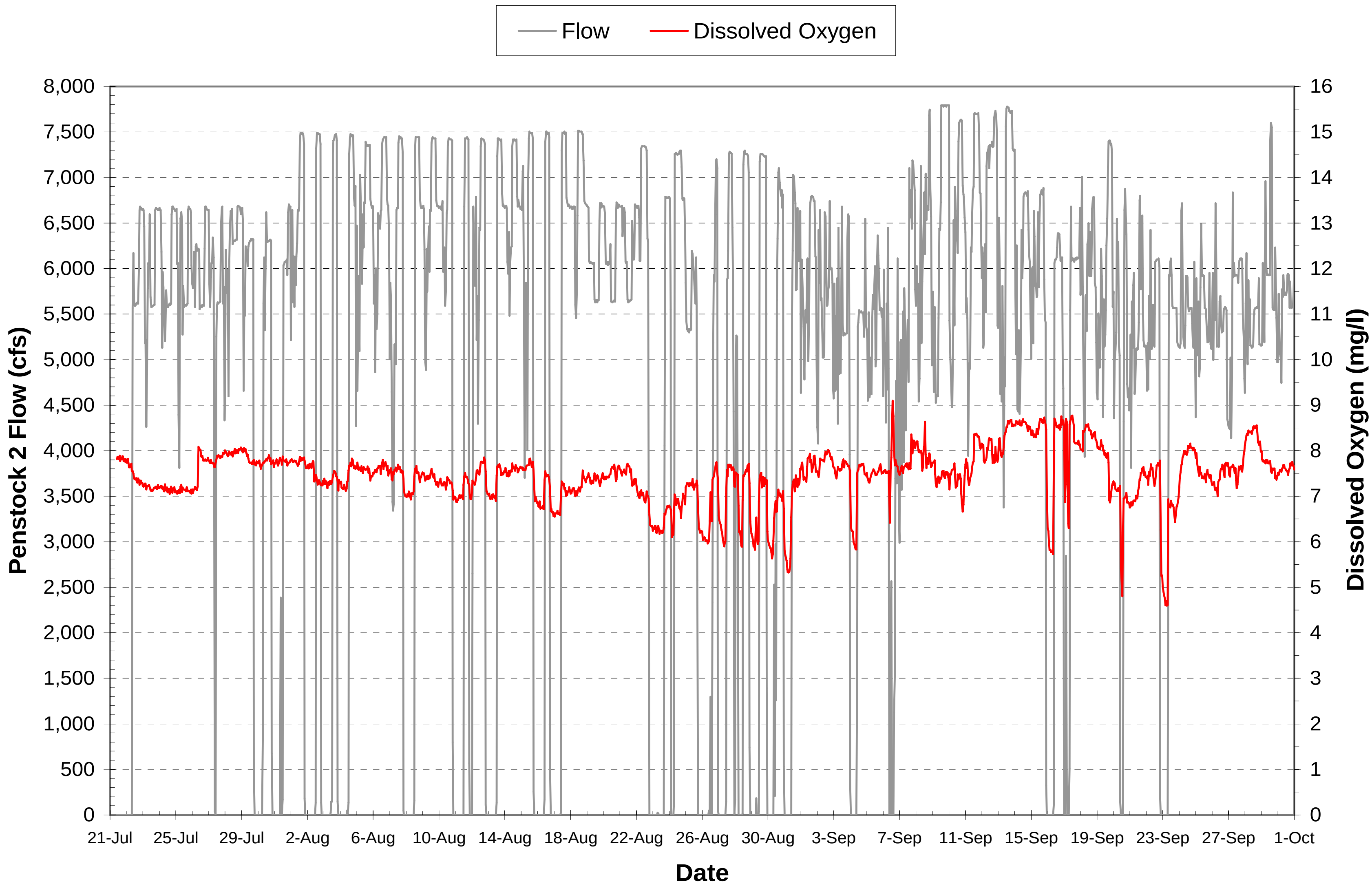

Plate 78. Average hourly discharge and dissolved oxygen concentrations measured in penstock 2 during the period July 21, 2005 through September 30, 2005.

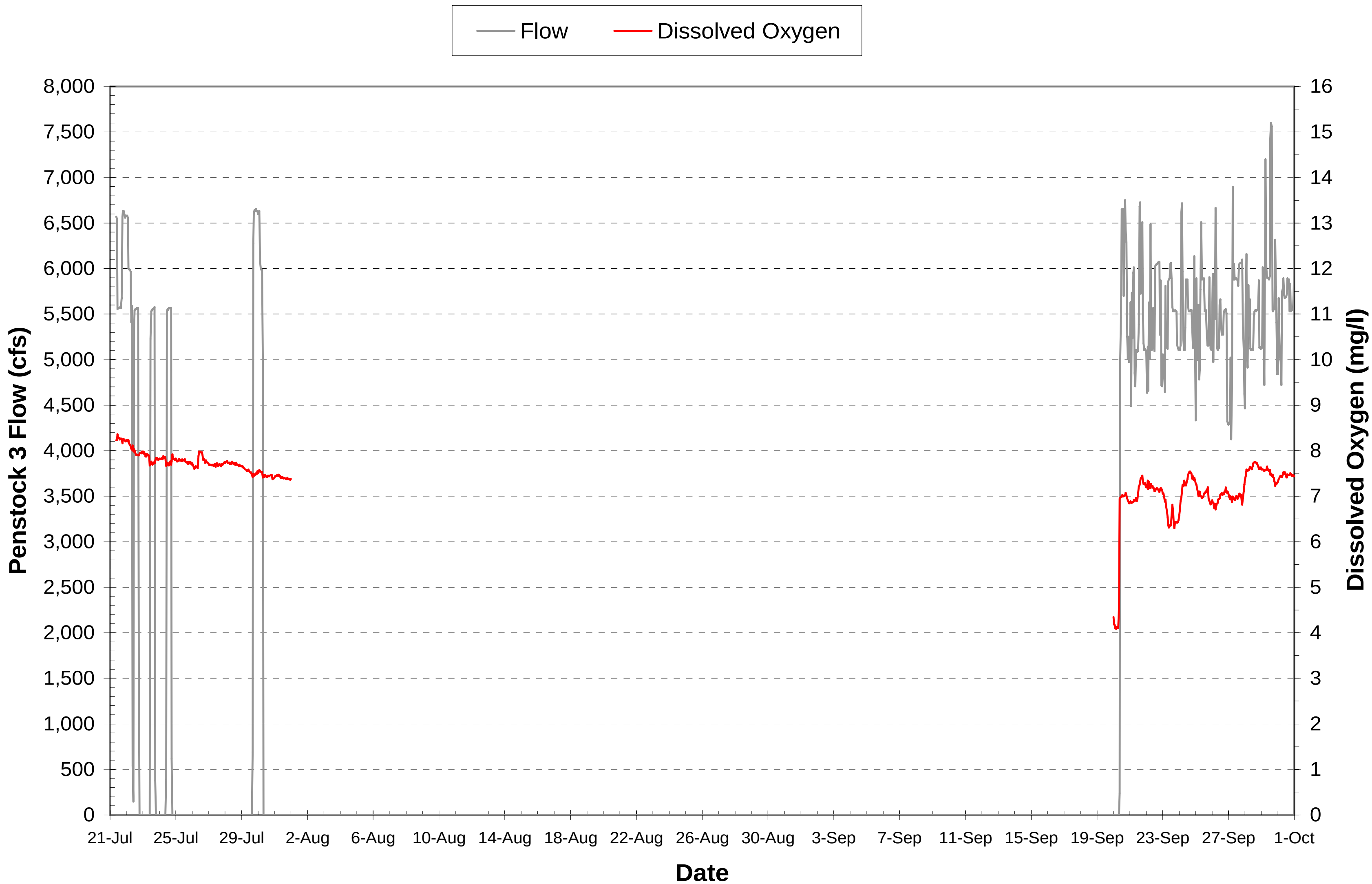

Plate 79. Average hourly discharge and dissolved oxygen concentrations measured in penstock 3 during the period July 21, 2005 through September 30, 2005.

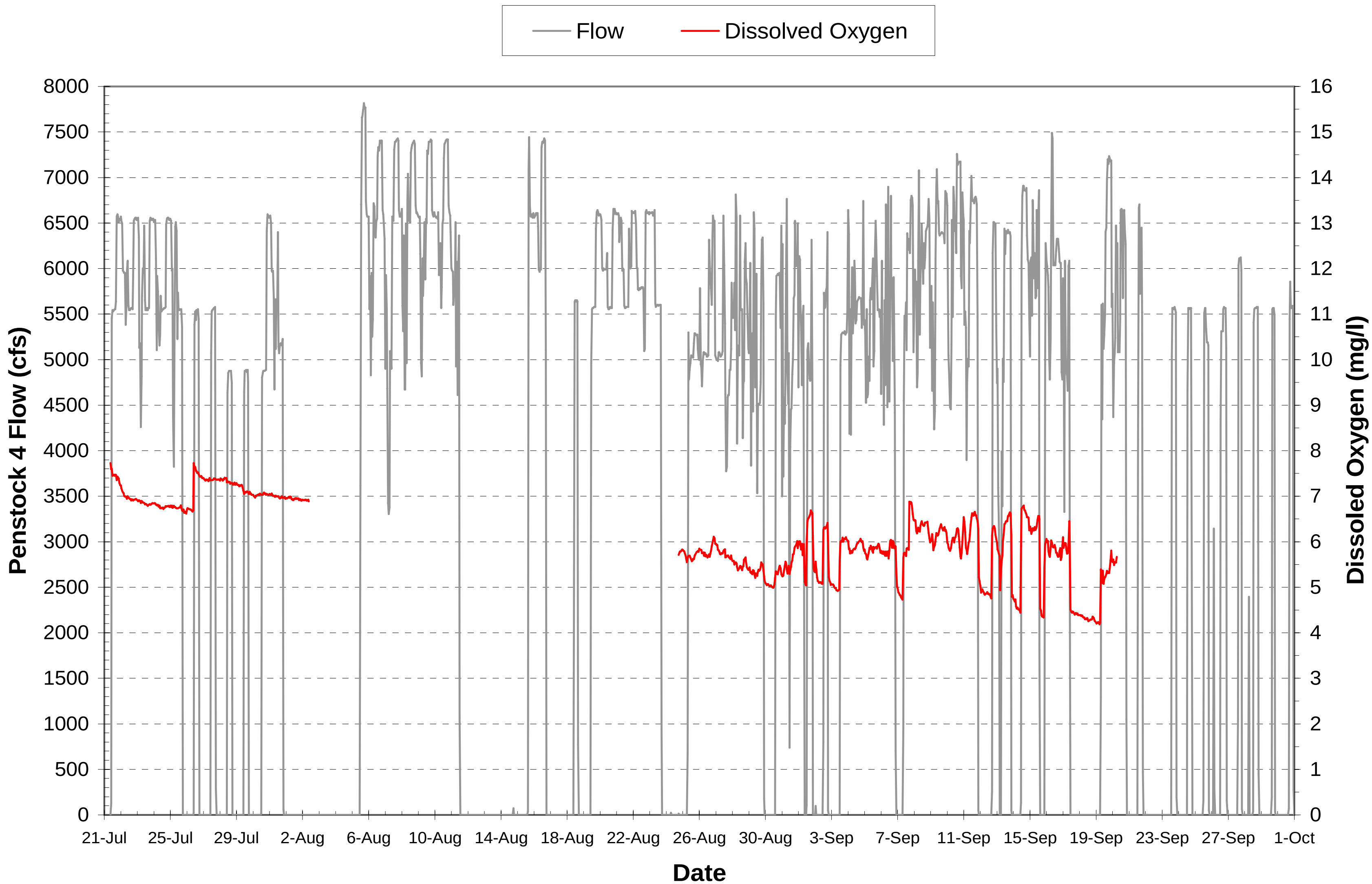

Plate 80. Average hourly discharge and dissolved oxygen concentrations measured in penstock 4 during the period July 21, 2005 through September 30, 2005.

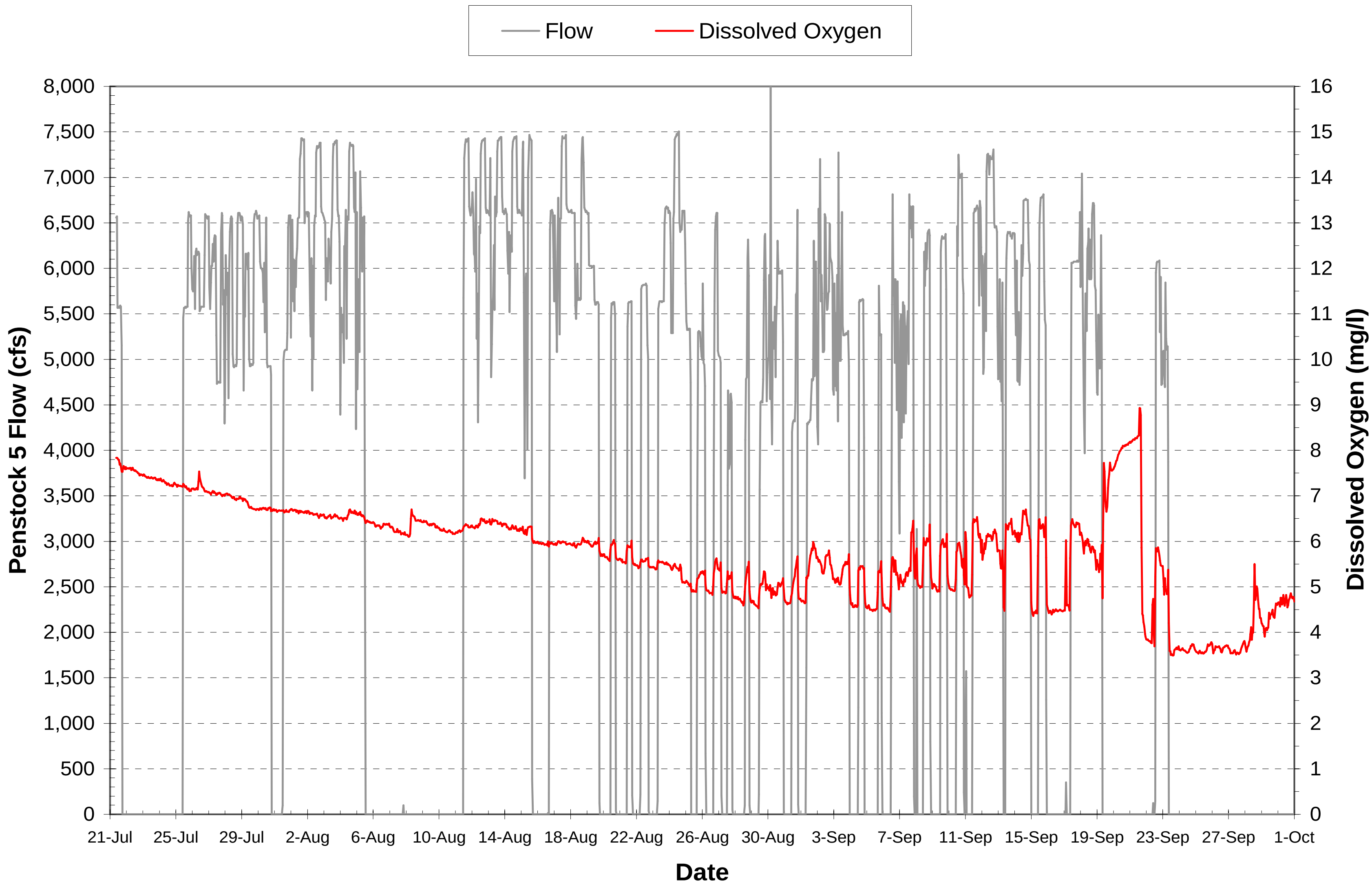

Plate 81. Average hourly discharge and dissolved oxygen concentrations measured in penstock 5 during the period July 21, 2005 through September 30, 2005.

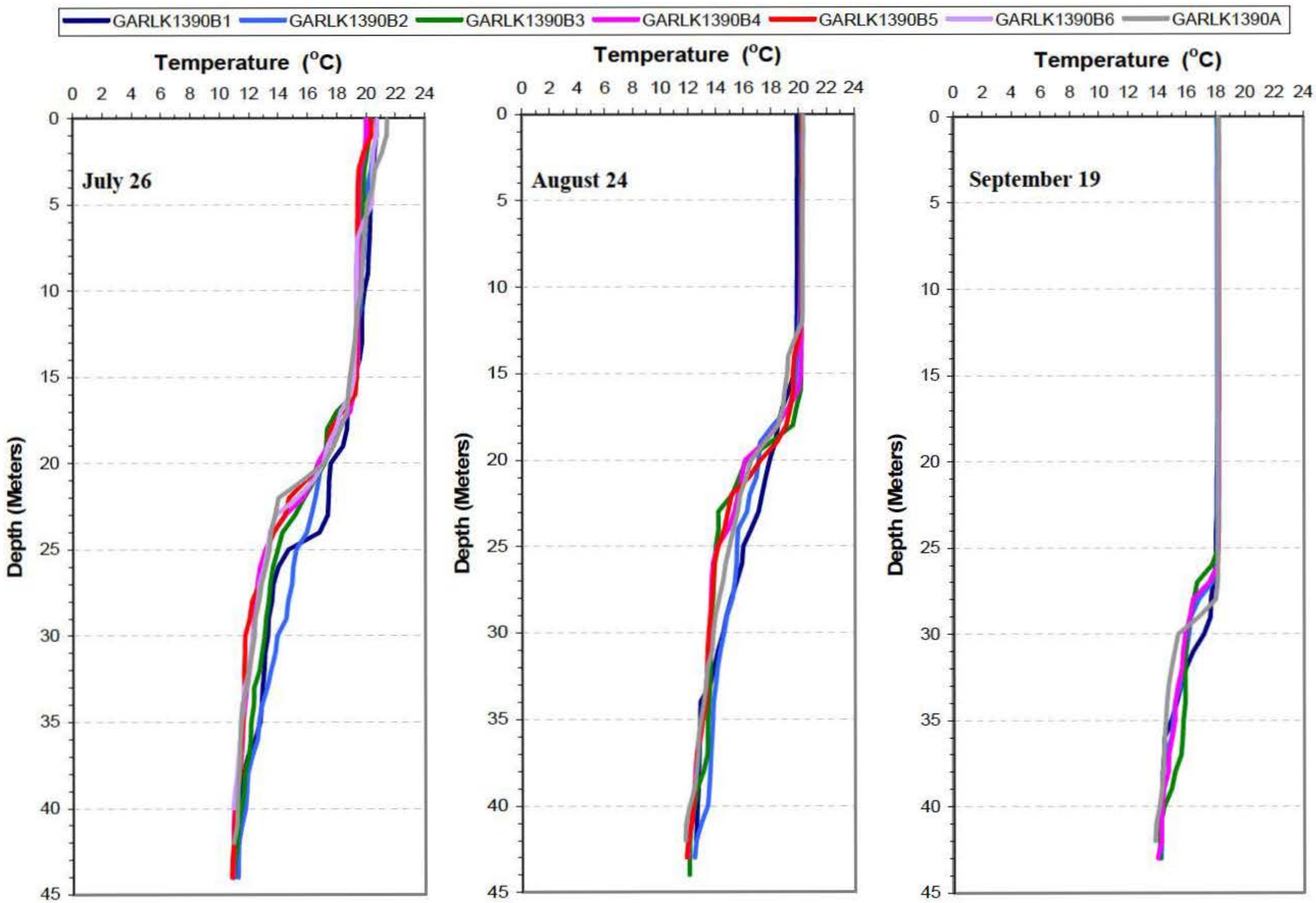

Plate 82. Temperature depth profiles measured along the submerged intake channel above Garrison Dam on July 26, August 24, and September 19, 2005.

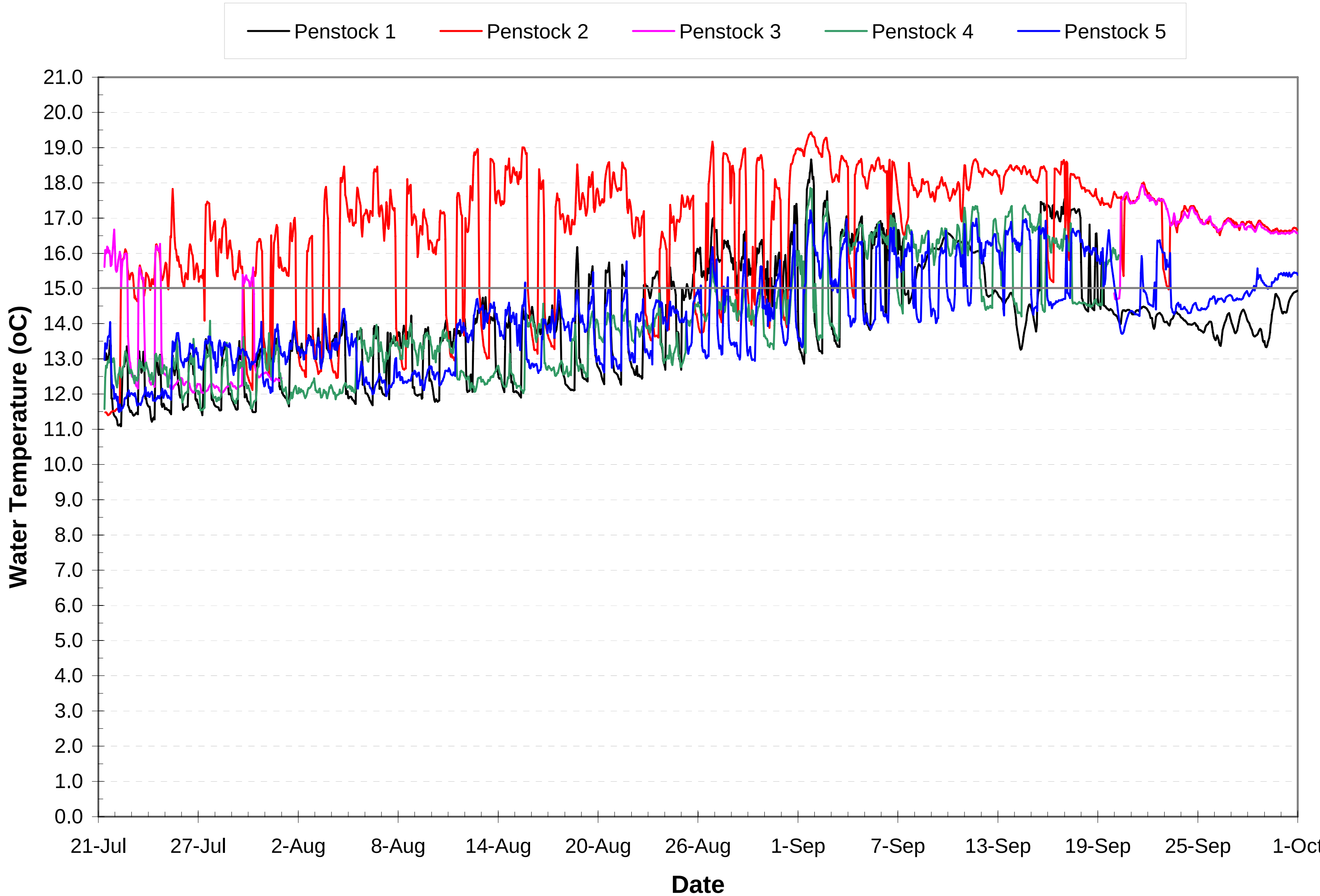

Plate 83. Average hourly water temperatures measured in penstocks 1, 2, 3, 4, and 5 for the period July 21 through September 30, 2005.

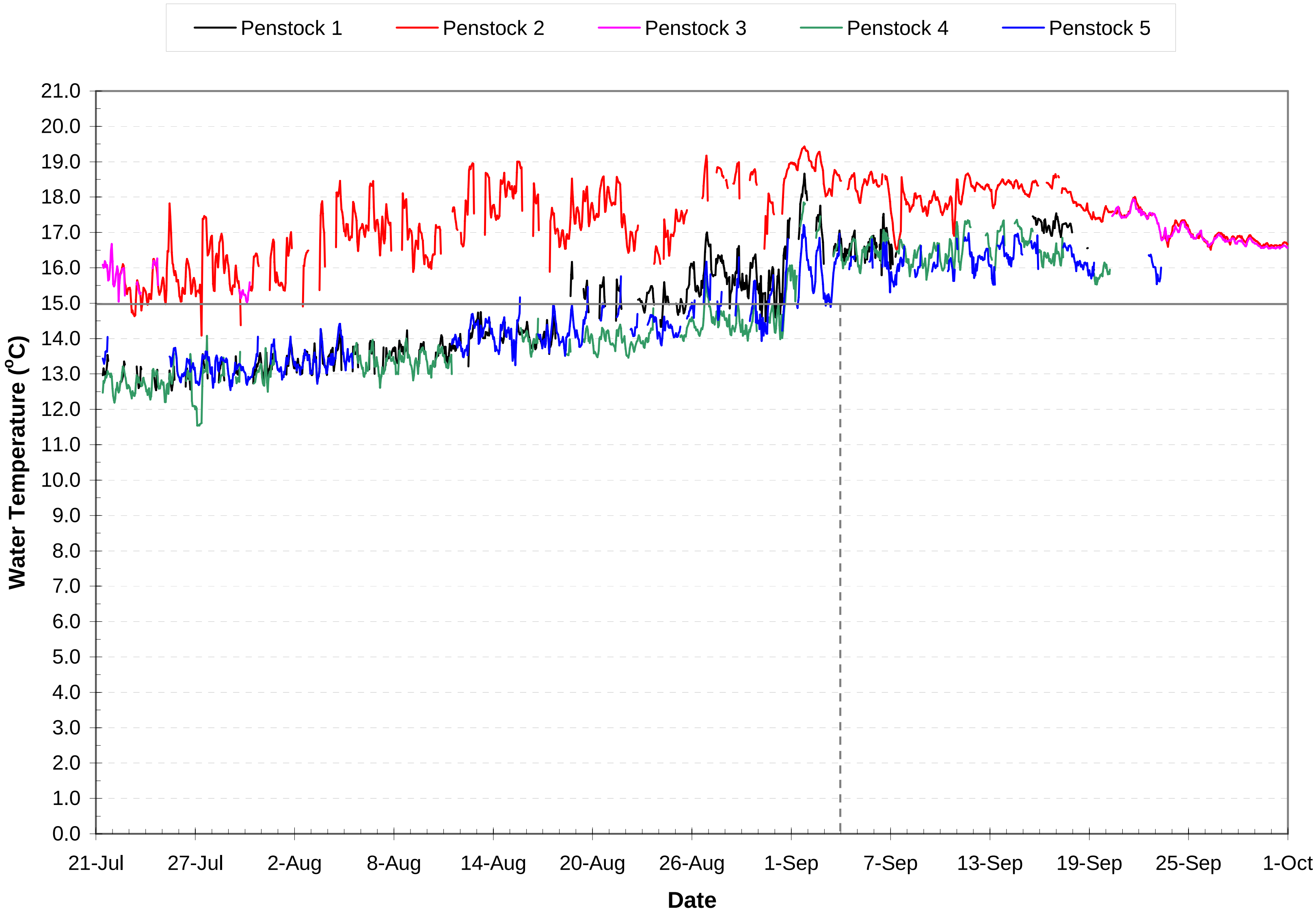

Plate 84. Average hourly dynamic water temperatures measured in penstocks 1, 2, 3, 4, and 5 for the period July 21 through September 30, 2005.

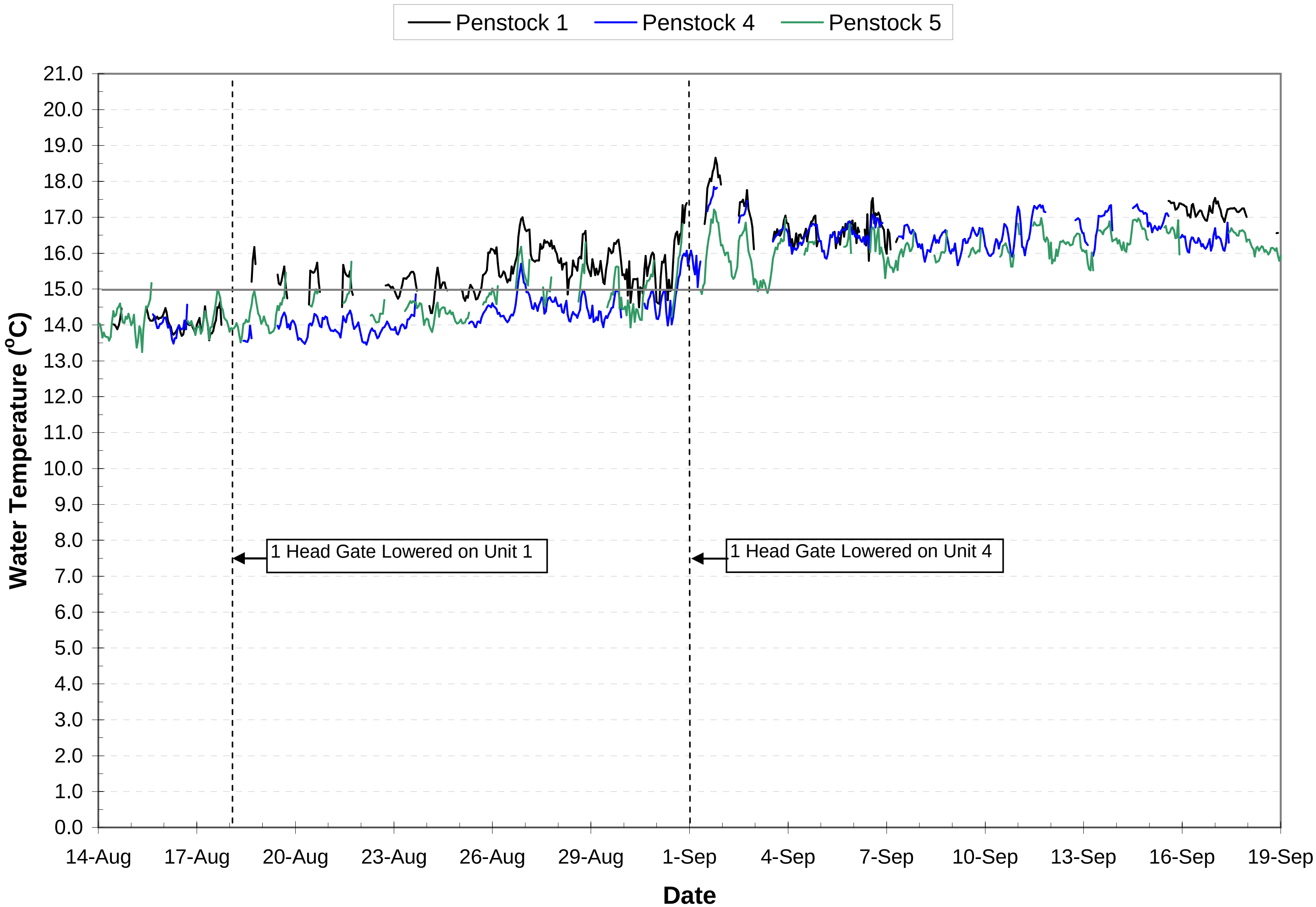

Plate 85. Average hourly dynamic water temperatures measured in penstocks 1, 4, and 5 for the period August 14 through September 19, 2005.